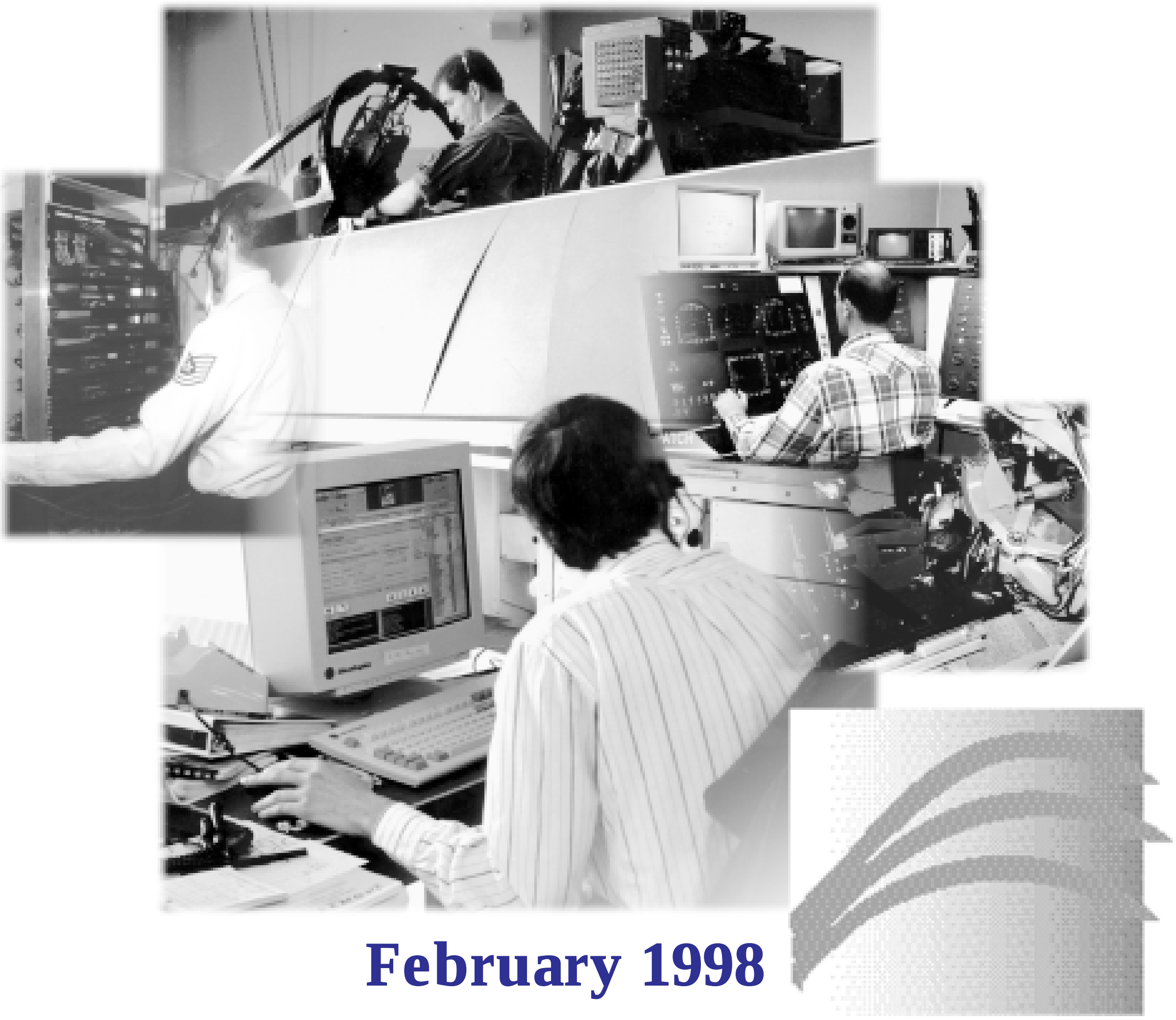
System Integration Test
Live Fly Phase
Executive Summary

This document has excerpts from the ***Live Fly Phase Final Report*** attached to it. Clicking on any **blue text** within the executive summary will take you to more detail from the full report. Clicking on **magenta text** within the report will take you back to the executive summary. **Bookmarks** are also provided at left for your convenience.



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LIVE FLY PHASE
EXECUTIVE SUMMARY

ES1.0 Introduction

The Live Fly Phase (LFP) of the System Integration Test (SIT) was conducted at Eglin Air Force Base (AFB), Florida, and Kirtland AFB, New Mexico, from November 1994 to October 1997. For the first time, inputs from two live aircraft were linked in near real-time to a missile hardware simulator in a laboratory facility. The Air Force Development Test Center (AFDTC) at Eglin AFB was a committed and an effective partner with the Joint Advanced Distributed Simulation (JADS) Joint Test Force (JTF) in the planning, preparation, and execution of the Live Fly Phase. This summary is designed to serve as a standalone document as well as part of this report. For that reason, the reader will find some duplication of verbiage and figures between the summary and the full report.

ES2.0 JADS Overview

The JADS Joint Test and Evaluation (JT&E) was chartered by the Deputy Director, Test, Systems Engineering and Evaluation (Test and Evaluation), Office of the Under Secretary of Defense (Acquisition and Technology) in October 1994 to investigate the utility of advanced distributed simulation (ADS) technologies for support of developmental test and evaluation (DT&E) and operational test and evaluation (OT&E). The program is Air Force led, with Army and Navy participation. The JTF manning includes 23 Air Force, 12 Army, and 2 Navy personnel. Science Applications International Corporation and Georgia Tech Research Institute provide contracted technical support. The program is scheduled for five years.

The JADS JT&E is directly investigating ADS applications in three slices of the T&E spectrum: a System Integration Test (SIT) which explores ADS support of air-to-air missile testing, an End-To-End Test which explores ADS support for command, control, communications, computers, and intelligence (C4I) testing, and an Electronic Warfare (EW) Test which explores ADS support for EW testing. The JTF is also chartered to observe, or participate at a modest level, in ADS activities sponsored and conducted by other agencies in an effort to broaden conclusions developed in the three dedicated test areas.

ES3.0 SIT Overview

The SIT is a two-phase test designed to examine the application of ADS technology in two architectures. The first phase employed an all-simulator architecture which incorporated a manned F-18 avionics lab (simulator) at China Lake Naval Air Station, California, as a shooter; a manned F-14 avionics lab (simulator) at Point Mugu, California, as a target; and the missile hardware-in-the-loop (HWIL) Simulation Laboratory (SIMLAB) at China Lake which generated AIM-9 missile flyouts and injected countermeasures (flares). Testing for this phase was completed in November 1996, and its final report was published in July 1997. The second phase of the SIT employed an architecture which incorporated a live F-16 shooter aircraft, a live F-16 target aircraft, and an Advanced Medium Range Air-to-Air Missile (AMRAAM) HWIL simulation hosted in the Eglin AFB Missile Simulation Laboratory (MISILAB). This document summarizes the LFP activities.

ES4.0 LFP Test Plan Overview

ES4.1 Purpose

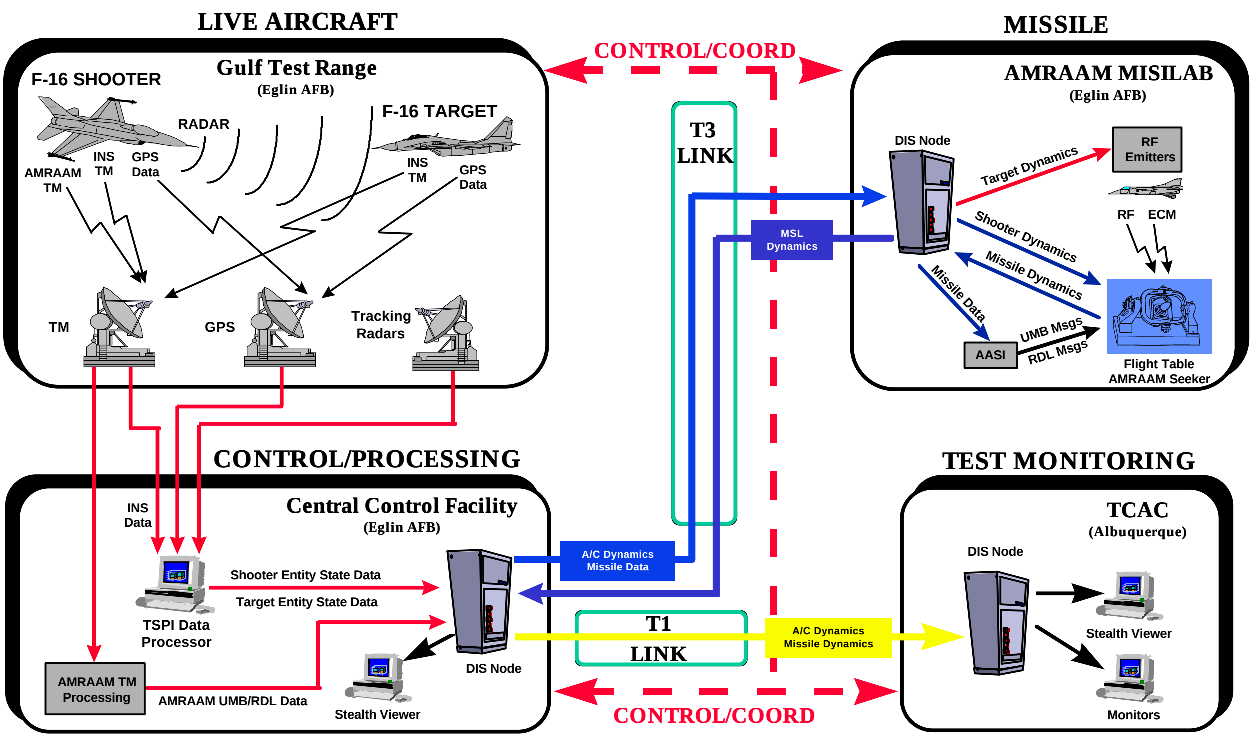
The LFP was designed to evaluate the utility of using ADS to support cost-effective testing of an integrated missile weapon/launch aircraft system. This slice of the test and evaluation (T&E) spectrum was an air-to-air missile test program that involved the simulation of an AMRAAM missile launch against a maneuvering target aircraft. The purpose of the LFP also included an evaluation of the capability of the JADS Test Control and Analysis Center (TCAC) to remotely monitor a distributed test of this type and analyze test results. In general terms, the purpose was to evaluate the quality and usability of AMRAAM test data from this distributed test architecture. The test objectives were:

- Objective 1: Assess the validity of AMRAAM data obtained in the LFP ADS configuration.
- Objective 2: Assess ability of LFP ADS configuration to perform AMRAAM testing.
- Objective 3: Assess ability to link live aircraft to missile HWIL simulation.
- Objective 4: Assess ability of LFP ADS configuration to support distributed missile testing.
- Objective 5: Develop legacy products from the SIT LFP results.

ES4.2 Approach

The LFP test concept was to replicate previous AMRAAM live fire profiles in an ADS configuration and compare missile results from the LFP trials to those from the live fire tests. In the LFP, ADS techniques were used to link two live F-16 aircraft representing the shooter and target to an AMRAAM hardware-in-the-loop (HWIL) laboratory representing the missile. The live shooter carried an AMRAAM emulator pod which represented the missile prior to launch. This configuration allowed data from live sources to drive the HWIL laboratory for more realistic missile results.

The LFP test configuration is shown in Figure 1. Global positioning system (GPS) and telemetry (TM) data were downlinked from the aircraft and passed to the Central Control Facility (CCF) at Eglin. GPS, inertial navigation system (INS), and tracking radar data for each aircraft were combined by the TSPI (time-space-position information) Data Processor (TDP) in the CCF to produce optimal entity state solutions. (These entity state data consisted of positions, velocities, accelerations, attitudes, and attitude rates.) The aircraft entity state data were transformed into distributed interactive simulation (DIS) protocol data units (PDUs) and transferred to the AMRAAM HWIL laboratory at the MISILAB over a T3 link.



A/C - aircraft
MSL - missile

AASI - Advanced Aircraft Simulation Interface
TCAC - Test Control and Analysis Center

UMB - umbilical
RDL - rear data link

Figure 1. Live Fly Phase Test Configuration

The shooter aircraft "fired" the AMRAAM in the MISILAB at the target and provided data link updates of the target position and velocity to the missile during its flyout. The AMRAAM seeker was mounted on a flight table and responded to radio frequency (RF) sources in the MISILAB which simulated the seeker return from the target, the relative motions of the target and the missile, and electronic countermeasures (ECM). A T1 link between the CCF and the JADS TCAC allowed JADS personnel to monitor the simulated intercepts.

ES4.3 Profiles

Two baseline engagement profiles (OP-612 and OP-617) were selected from the AIM-120A follow-on operational test and evaluation (FOT&E) test series (conducted from March 1993 to February 1995).

These engagement geometries were the basis for all trials in the LFP. The selection of these profiles was based on three factors: (1) the shooter was an F-16, (2) several AMRAAM test objectives were represented, and (3) sufficient live fire data were available for verification and validation (V&V) of the LFP trials. The profiles are depicted in Figure 2.

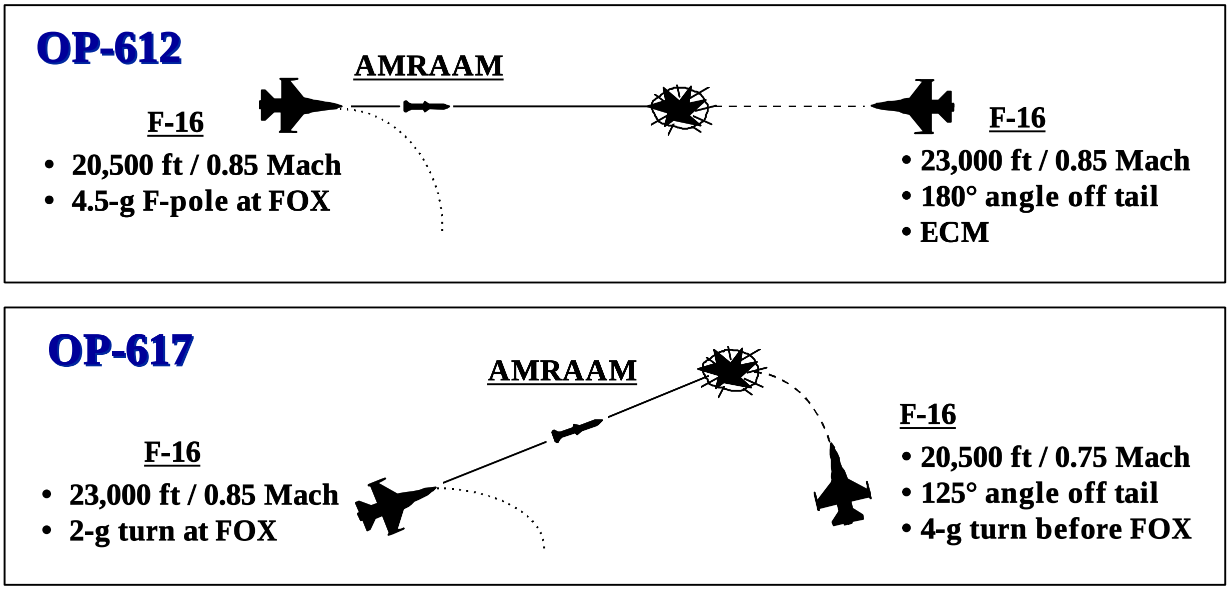


Figure 2. Modified Scenarios (Live Fire Profiles OP-612 and OP-617)

As the primary scenario for verification, validation, and production testing, OP-612 was selected for its simplicity (head-on, lookup/shootup, nonmaneuvering target), in order to allow testers to pinpoint sources of problems more rapidly. This scenario also included ECM against the missile only in a relatively benign engagement.

The secondary profile for validation came from the OP-617 flight test from FOT&E(2). This scenario was selected because it introduced some complexities which addressed additional AMRAAM DT/OT test objectives: off-aspect, lookdown/shootdown, and maneuvering target. A second fire control radar (FCR) mode was used, and there was no ECM in this scenario. The launch range for this profile was increased by a factor of about four from the OP-617 value in order to require rear data link (RDL) updates during the missile flyout.

The aircraft velocities had to be reduced for both scenarios, due to restrictions on the GPS pods. Also, the aircraft altitudes had to be significantly raised in order to maintain good telemetry links to the ground receivers. However, the shooter-target differences in velocities and altitudes were maintained.

ES4.4 Instrumentation

One of the major distinguishing characteristics of a distributed testing architecture, as opposed to a distributed training architecture, is in the degree of instrumentation. The LFP architecture was instrumented to a level which supported the measurement of latency values, synchronization differences, position transformation errors, missile seeker performance, and the whole gamut of network performance measures. The aircraft instrumentation included a simulated missile pod, GPS pods, telemetry antennas, and cockpit video recorders. The network instrumentation included specialized data loggers, two-dimensional and three-dimensional graphics displays, network health and status software, and data servers.

ES4.5 Planned Testing

Initially, there was a series of eight risk reduction (RR) tests planned to methodically integrate the Eglin assets into an ADS architecture. The RR tests broke down the large problem of verification into smaller, executable steps.

Next, the LFP test objectives were to be accomplished during three live flight test missions. The mission goals were to check out and validate performance of the subsystems, validate the overall LFP ADS configuration, provide validation data for both the OP-612 and OP-617 scenarios, and assess variations on the fire control radar modes.

Monte Carlo runs were planned as part of the LFP V&V effort. The Monte Carlo runs involved replaying recorded flight data into the MISILAB. Selected ADS-linked runs would be replayed, in addition to data from the original OP-612 and OP-617 flight tests, to get a new series of 25 flyouts apiece. The Eglin missile experts would then judge the validity of the ADS-linked results by comparing them to the data from the Monte Carlo runs.

ES5.0 LFP Test Results

ES5.1 Schedule

The baseline schedule was planned to end in July 1997, while the actual schedule ended in October 1997. The eight risk reduction tests expanded to ten because of technical problems with the TDP and telemetry. RR#7 was changed from a ground to a flight test mission because of problems with simulated data. RR#8 through RR#10 were added as live flight integration missions. The fixes for the TDP and telemetry problems were tested on these flights, and they served to verify the full-up LFP configuration. That added data helped to ensure the success of Mission #1; it was determined that all the objectives were met, so Missions #2 and #3 were canceled. The Monte Carlo test was successfully accomplished on 29/30 October 1997.

ES5.2 Evaluation of Test Objectives

ES5.2.1 Validity of AMRAAM Data

Results of the verification and validation analyses support the conclusion that the LFP ADS configuration provided valid AMRAAM data and a valid testing environment for an integrated launch aircraft/missile weapon system.

The verification results showed that the facilities were properly linked, all components operated properly, and the missile in the MISILAB HWIL facility responded correctly to the inputs received.

The validation results showed that the MISILAB standalone simulations of the OP-612 engagement were valid. This reaffirmed the expectation that the MISILAB HWIL simulation in a standalone configuration would provide valid AMRAAM results. The validation process also revealed that the MISILAB HWIL facility provided proper and valid responses to its inputs. The Eglin missile experts reported that AMRAAM data from the LFP ADS configuration exhibited similar properties as those observed in actual AMRAAM flight tests.

ES5.2.2 Ability to Perform AMRAAM Testing

The LFP ADS configuration would be able to accomplish some live AMRAAM testing objectives, within certain limitations. The AMRAAM test objectives that ADS can help evaluate include launch aircraft support of the missile, lookdown/shootdown scenarios, various target aspects, maneuvering targets, and ECM. This ADS concept has limitations with target-in-clutter situations, maneuver-to-beam scenarios, intercepts resulting in high line-of-sight rates, and synchronous ECM techniques. For those AMRAAM test objectives and scenarios for which the LFP ADS configuration could be used, there are advantages to using the ADS configuration.

- Quick-look results would be available immediately after each pass.
- Highly accurate TSPI data would allow an accurate evaluation of targeting message accuracy and probability of successful guidance.
- The analyst-in-the-loop would ensure efficient use of live range time.
  - This would be especially advantageous for testing ECM techniques.
- Live fire missile tests could be effectively rehearsed.

ES5.2.3 Ability to Link Live Aircraft to Missile HWIL Simulation

The TDP solution met the MISILAB accuracy requirements of 5 meters in position and 1 meter per second in velocity whenever the relatively accurate aircraft INS data were input to the TDP. The TDP solution accuracy was much better than can be achieved with standard range TSPI systems during live fire missile tests.

The shooter and target entity state data were correctly aligned to the missile reference frame.

The required degree of data synchronization was achieved. The shooter and target entity state data were synchronized to each other, to the MISILAB simulation, and to the umbilical and RDL messages to within acceptable tolerances.

The latencies during Mission #1 were relatively stable and consistent, but fairly large. The total latency of the MISILAB simulation was about 3.1 seconds, including about 2.5 seconds for the TDP processing and smoothing and 0.6 seconds for synchronization at the MISILAB. Data processing (not the transmission delays) was the major factor in determining the total latency.

5.2.4 Ability of LFP ADS Configuration to Support Distributed Missile Testing

Availability was excellent when using the production ADS configuration. For the network, there were no operational mission hardware or software failures during more than 3.5 hours of testing (RR#10 and Mission #1), resulting in an availability of 100 percent.

Reliability expressed in terms of successfully linked runs with valid flyouts was 82 percent during the final test mission (14 of 17 good runs), while the valid missile flyout rate was about 45 percent during the integration missions. Runs failed for a wide variety of reasons involving people, telemetry dropouts, computers, instrumentation, time stamping problems, and simulator performance.

The T3 and T1 links used provided ample bandwidth, and there was no loss of connectivity during the LFP trials.

There were essentially no ADS-induced errors resulting from the LFP ADS architecture, and the DIS PDUs were very adequate for all data exchanges in the LFP.

Test control procedures were refined throughout the risk reduction process and worked well during testing. Tactical aircraft control of live aircraft had to be performed at the range (due to range policy which was driven primarily by range safety issues). Since the aircraft controller and the instrumentation controller were at the Eglin CCF, this was also the best location for the JADS test director to take part in troubleshooting and decision making. Situational awareness of the JADS test director could have been improved with another communication line connecting him with JADS project members.

ES5.2.5 LFP Costs

The programmatic costs for the SIT LFP were broken down into individual mission costs and overall program costs. Typically, a two-hour live mission (RR#8 through RR#10 and Mission #1) consisted of 17 passes and cost between $54 thousand and $57 thousand, which included the costs for two F-16s, range operators, many CCF processors, and the real-time MISILAB flyouts. The Monte Carlo validation runs over two days cost approximately $50 thousand and provided validation data for six different profiles.

Overall, the total cost of the LFP was approximately $4.1 million, which included all labor, hardware, software development, and network costs. The total funds sent from JADS to the test range were approximately $1.5 million, including upgrades, management, integration, flight testing, analysis, and reporting. The JADS expenditures equaled about $1.8 million, including TCAC hardware and software, network equipment, T1 leasing, labor, and travel. An additional $800 thousand was spent by the test range and the AMRAAM Program Office for Eglin software development and for the Advanced Aircraft Simulation Interface (AASI) procurement.

ES5.3 Fulfillment of Test Objectives

All test objectives (see paragraph 4.1) were met.

ES6.0 Lessons Learned

ES6.1 Technical

Standalone simulation facilities can require significant (and time consuming) software changes before effective linking is possible.

Live risk reduction missions were needed for effective integration testing. Attempts to use a ground configuration involving the PRIMES facility were unsuccessful, due to problems with simulated GPS data. Also, the use of live aircraft with real data uncovered linking problems that would not have been found in a ground test rehearsal. The live flights uncovered telemetry problems, fuel tank shielding, out-of-order missile data, and GPS data problems.

Linking may require special purpose interfaces, and their development must be factored into test planning. The LFP ADS configuration required a special purpose interface (the AASI) to link the shooter aircraft-generated targeting messages to the HWIL missile in real time, and development of the interface drove the test schedule.

A full understanding of telemetry limitations was needed. The range and aircraft telemetry experts needed to decide on issues for the best telemetry reception, such as aircraft pod and fuel tank configurations, profile directions, and altitude or line-of-sight considerations.

Key interfaces and data processing systems (such as the AASI, TDP and network interface units) need realistic integration testing and mission loading to shake out potential problems. The most realistic testing was performed by either replaying data recorded from live missions or by conducting an actual live integration mission.

Having accurate requirements for network connectivity identified early in the program was very advantageous for linking the distributed facilities. This early planning allowed early network integration testing, well ahead of other facility check outs.

Merging several TSPI sources in the TDP was advantageous; the combination of sensors coasted through most GPS dropouts to allow a more consistent (and ultimately accurate) solution. This also allowed stringent TSPI accuracy requirements to be met.

ES6.2 Infrastructure and process

The series of risk reduction tests was extremely useful for progressing through the many levels of integration work. The Eglin members designed a building block approach to check out interfaces at the lowest level, then add one or two resources at a step to integrate the linked configuration.

Lab replays served as an excellent method of rehearsal and check-out. By replaying a set of prerecorded data, all the Eglin team members could participate in a laboratory replay session. This was an excellent method to rehearse test procedures, work out technical and procedural issues, and troubleshoot problems.

Existing range procedures had to be modified for ADS. The existing Eglin test procedures were only written for individual facilities, so a new combined checklist was created for ADS applications with several linked assets.

Pilots should be involved in scenario setup. This was beneficial for achieving the correct launch parameters.

A premission briefing is needed before each mission, as it was critical for coordinating the many network and flight test issues.

The T1 link to the TCAC was excellent for data transfer from Eglin to Albuquerque. This ease of transfer allowed data analysis to start very soon after each mission and allowed detailed results to be known earlier.

Live aircraft operations with linked facilities required more contingency planning to quickly decide on alternatives. The initial list of go/no go criteria was expanded to include alternatives in case of failures or degraded assets. Having this contingency plan spelled out in advance helped the test director make rapid, well-informed decisions to get the most productive use out of the remaining mission time.

A strong program manager or system integrator was needed to oversee test bed preparation. The AFDTC manager had to grasp the technical and administrative issues involved and proactively resolve the problems.

Live aircraft must be locally controlled, as the test range safety policy required that tactical control of aircraft over their airspace be performed at the Eglin CCF.

Project and scenario control were best performed at the test range. The JADS test director had to be collocated with the CCF coordinator and the range aircraft controller in order to see problems as they occurred and to be part of the decision making process.

Three voice communication networks were needed to support more than 30 people at various locations, and a fourth network could have further aided decision making.

Using a graphical two-dimensional display greatly improved the situational awareness of participants at each testing site.

Verification of test range assets is a test range responsibility. The range should verify range assets before use by external customers, and these same verified procedures should be used during ADS testing.

A T1 circuit was the best option for the LFP wide area network, but the contract was somewhat expensive and had difficult initiation and termination clauses with long lead times.

ES7.0 Conclusions

The LFP configuration produced valid missile test data and has a useful place in a missile test program. This testing method can effectively complement both live fire shots and captive carry missions for a variety of, but not all, test conditions.

Although this particular test architecture would not support valid closed-loop interactions between the missile and target, it does support the open-loop scenarios typical of live testing and closed-loop interactions between the shooter and the target for such purposes as test rehearsal and tactics development.

Preparation, setup, calibration, and check-out activities are more challenging and time consuming in a distributed environment. The Eglin agencies involved had never been linked before, so there were some development and interagency hurdles to overcome. The technology's use in T&E is still in its infancy, and the test agencies involved in the integration activities had to climb a steep learning curve. Now there are many test range personnel with some ADS experience, so if another tester were to work with the Eglin agencies, we believe the preparation timelines would be considerably shorter that they were the first time.

The development of a distributed T&E architecture is not a "plug-and-play" exercise. In the near term, the elements available for linking in a given architecture will almost certainly not be designed to be linked. That means that the burden for making linked architectures work falls upon the interfacing and integrating activities.

2.0 Live Fly Phase Test Plan Overview

2.1 Live Fly Phase Purpose

The live fly phase (LFP) was designed to evaluate the utility of using advanced distributed simulation (ADS) to support an air-to-air missile test program and involved the simulation of an advanced medium range air-to-air missile (AMRAAM) missile launch against a maneuvering target aircraft. The purpose of the LFP also included an evaluation of the capability of the Joint Advanced Distributed Simulation (JADS) Test Control and Analysis Center (TCAC) to remotely monitor a distributed test of this type and analyze test results.

2.2 Test Approach

The LFP test concept was to replicate previous AMRAAM live fire profiles in an ADS configuration and compare missile results from the LFP trials to those from the live fire tests. In the LFP, ADS techniques were used to link live aircraft representing the shooter and target to an AMRAAM hardware-in-the-loop (HWIL) laboratory representing the missile. The live shooter carried an AMRAAM emulator pod which represented the missile prior to launch. This configuration allowed data from live sources to drive the HWIL laboratory for more realistic missile results.

The LFP ADS configuration had both developmental test (DT) and operational test (OT) characteristics. There was a DT flavor because a HWIL facility was used to simulate the missile. This allowed the detailed performance of missile subsystems to be monitored, typical of a DT test. The OT characteristics of the System Integration Test (SIT) resulted from the use of actual aircraft performing operationally realistic engagements. Of particular value was that the launch aircraft fire control radar operated in the real environment and was affected by weather, clutter, and other variables for which good digital models do not exist. This meant that the test was more representative of the performance of the integrated weapon system in the actual operating environment, instead of the weapon alone.

The AMRAAM system has undergone extensive initial operational test and evaluation (IOT&E) by the Air Force, and follow-on operational test and evaluation (FOT&E) by both the Air Force and the Navy. The LFP test approach was tied to that previous testing and included the following steps:

- The flight profiles and AMRAAM test objectives selected for the LFP were based on a subset of the previous AMRAAM live tests.

- Results from the LFP ADS configuration were evaluated to determine their validity. This evaluation was based on quantitative and qualitative comparisons of the missile results from the LFP to those from the live fire tests.

- Any discrepancies due to the ADS implementation were identified and assessed as to their significance. Requirements for resolving significant discrepancies in future ADS implementations were identified.

2.3 LFP Test Objectives

The objectives of the LFP testing are described and discussed in the following sections.

2.3.1 Test Objective 1: Assess the validity of AMRAAM data obtained in the LFP ADS configuration

Under this objective, the LFP assessed the validity of AMRAAM data generated in the ADS configuration. This was measured by determining whether or not the LFP was capable of providing valid AMRAAM data. This assessment relied on evaluation of the data by analysts from the AMRAAM test program working together with the JADS analysts to execute the validation procedures for the SIT LFP.

2.3.2 Test Objective 2: Assess ability of LFP ADS configuration to perform AMRAAM testing

This test objective verified the ability of the ADS configuration to accomplish live AMRAAM testing as specified by AMRAAM test program documentation. The evaluation addressed the ability to acquire all data normally obtained in live fire AMRAAM testing while repeating actual scenarios from FOT&E(2) testing.

2.3.3 Test Objective 3: Assess ability to link live aircraft to missile HWIL simulation

This assessment addressed the ability of the ADS configuration to support stringent constraints derived from interfacing live aircraft with an HWIL facility in a manner adequate to support T&E. These constraints were evaluated in the following subobjectives.

2.3.3.1 Test Subobjective 3-1: Assess ability to provide required TSPI accuracy

Time-space-position information (TSPI) data from the launch and target aircraft were used to drive the missile HWIL laboratory. Proper response of the simulation required a near-real-time TSPI precision which pushed the limit of the best TSPI systems currently available. The ability to provide the TSPI accuracy required by the HWIL laboratory was evaluated.

2.3.3.2 Test Subobjective 3-2: Assess ability to provide required reference frame alignment accuracy

TSPI data from the launch and target aircraft had to be accurately aligned to the reference frame of the missile in the HWIL facility. This required careful coordinate transformations and time alignment. The ability to perform accurate TSPI alignment was evaluated.

2.3.3.3 Test Subobjective 3-3: Assess ability to provide required data synchronization

Data from the live aircraft had to be carefully synchronized before linking to the missile HWIL laboratory. The data are time stamped when generated and then put onto the network when the network is ready to accept the information. Several pieces of information which were generated simultaneously were received sequentially. Also, data generated at any given time may be received out of time sequence with other related data. The receiving node must have a way of resynchronizing the information it needs to perform its function. The LFP examined these issues.

2.3.3.4 Test Subobjective 3-4: Identify and quantify latency of LFP ADS configuration

Synchronization of data input to the missile HWIL simulation in the LFP was achieved by delaying some of the data sources until processing and transmission of all required data was completed. As a result, the linked simulation in the Missile Simulation Laboratory (MISILAB) ran behind real time. Time delay, or latency, did not, by itself, affect the validity of the LFP results because the scenarios tested in the LFP did not involve any closed-loop interactions between the missile and target.

However, a future desired application of ADS is to allow “closing the loop” between the missile and the target aircraft. This would allow evaluation of reactive countermeasures and certain electronic countermeasures (ECM) techniques. In this case, latency would have a major impact on the validity of the results for such scenarios. The LFP identified and quantified contributions to total latency, so that restrictions on the future applications of the LFP ADS configuration could be determined.

2.3.4 Test Objective 4: Assess ability of LFP ADS configuration to support distributed missile testing

This test objective is broken into subobjectives as follows.

2.3.4.1 Test Subobjective 4-1: Assess capability of ADS network to provide bandwidth and connectivity required for LFP tests

This subobjective assessed the ability of the LFP ADS network to support data exchange for AMRAAM testing when it is operating. Any connectivity losses between nodes was to be identified, and the rate of data flow was quantified as the percentage of available bandwidth utilized on each connection.

2.3.4.2 Test Subobjective 4-2: Assess the effects of ADS-induced errors on LFP test results validity

Whereas Subobjectives 3-1 through 3-4 <u>measured</u> the errors in data, this subobjective discussed the <u>impacts and effects</u> on the test validity. The ADS-induced errors which were considered included protocol data units (PDUs) not received at the appropriate node or received out of order, PDUs or missile telemetry corrupted during transmission, and TSPI data errors introduced during the coordinate transformations required for Entity State PDUs.

2.3.4.3 Test Subobjective 4-3: Assess adequacy of DIS protocol data units for LFP test

The SIT LFP utilized standard distributed interactive simulation (DIS) PDUs, where feasible, for transferring information between simulation nodes. This was desirable in order to maintain an open architecture in which other DIS-compliant live test ranges or simulation facilities could replace those used in the LFP in future ADS tests of this type. The adequacy of the standard DIS PDUs to provide the required data accuracy, synchronization, and minimal latency was assessed.

2.3.4.4 Test Subobjective 4-4: Assess reliability, availability, and maintainability of ADS network

This subobjective assessed the degree to which the LFP ADS network was available to support AMRAAM testing and could be maintained.

2.3.4.5 Test Subobjective 4-5: Assess capability to remotely control and monitor test

This subobjective assessed the capability of the JADS TCAC to operate as a secondary control node over a distributed test of this type, and to remotely monitor and analyze test results.

2.3.5 Test Objective 5: Develop legacy products from the SIT LFP results

This test objective is broken into subobjectives as follows.

2.3.5.1 Test Subobjective 5-1: Document programmatic costs for the SIT LFP

This subobjective documented the costs of all phases of the LFP, broken down into categories of planning, design and development preparations, test rehearsal, test execution, analysis, and reporting. This information may assist future test managers with cost effectiveness aspects and budgetary constraints of ADS testing.

2.3.5.2 Test Subobjective 5-2: Document test procedures for the SIT LFP

This subobjective documented the procedures used to execute the LFP missions. This included procedures for planning and scheduling live aircraft, range assets, and supporting facilities. Shortcomings, lessons learned, and recommended changes for future applications are included.

2.4.1-2.4.2 Removed. Contact JADS.

2.4.3 Test Configuration

2.4.3.1 Overall Configuration

In the LFP, the shooter and target were represented by live aircraft and the missile by an HWIL laboratory. ADS techniques were used to link two live F-16 fighter aircraft flying over the Eglin Gulf Test Range to the AMRAAM AIM-120 HWIL simulation facility at Eglin Air Force Base, Florida. The LFP test configuration is shown in Figure 2.4.3-1. Global positioning system (GPS) and telemetry data were downlinked from the aircraft and passed to the Central Control Facility (CCF) at Eglin. GPS, inertial navigation system (INS), and tracking radar data for each aircraft were combined by the TSPI Data Processor (TDP) in the CCF to produce optimal entity state solutions. The aircraft entity state data were transformed into DIS PDUs and transferred to the AMRAAM HWIL laboratory at the MISILAB over a T3 link. The shooter aircraft "fired" the AMRAAM in the MISILAB at the target and provided data link updates of the target position and velocity to the missile during its flyout. The AMRAAM seeker was mounted on a flight table and responded to RF sources in the MISILAB which simulated the seeker return from the target, the relative motions of the target and the missile, and ECM. A T1 link between the CCF and the JADS TCAC allowed JADS personnel to monitor the simulated intercepts.

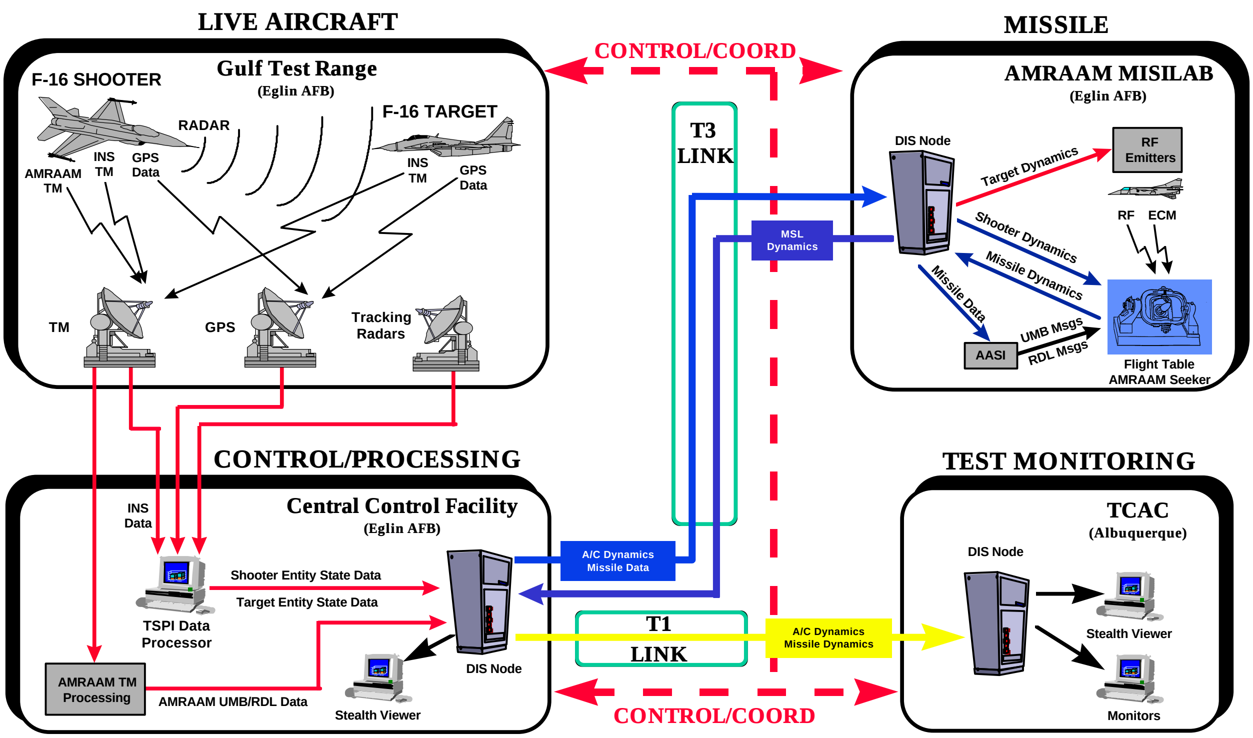


Figure 2.4.3-1. Live Fly Phase Test Configuration.

The actual umbilical (umb) and data link messages from the shooter aircraft were used to initialize, launch, and update the missile in the MISILAB during each simulated engagement. The shooter carried an Integration Test Vehicle (ITV) pod which emulated the AMRAAM missile in its pre-launch configuration, and AMRAAM telemetry from the pod was downlinked and processed by the CCF. The telemetry was converted into DIS PDUs and transferred to the MISILAB over the T3 link. The messages were then reconstructed and synchronized to the aircraft TSPI data by the Advanced Aircraft Simulation Interface (AASI) in the MISILAB.

The MISILAB used the live target TSPI data to dynamically control the target representation in the RF scene presented to the AMRAAM seeker in the MISILAB. As the AMRAAM underwent its simulated flyout, its trajectory information (position versus time) was passed as Entity State PDUs back from the MISILAB to the CCF for display to test operators and analysts.

The test runs were controlled from the CCF. The control center ensured that all players were ready for each run and issued the commands to start and stop the passes. PDUs were processed at the TCAC to provide JADS personnel with real-time stealth node viewing of the simulated engagement. Coordination of the test between the CCF and the TCAC was done via voice communications.

2.4.3.2 Processing and Data Flow

The CCF segment of the processing and data flow is shown in Figure 2.4.3.2-1, and the MISILAB segment is shown in Figure 2.4.3.2-2.

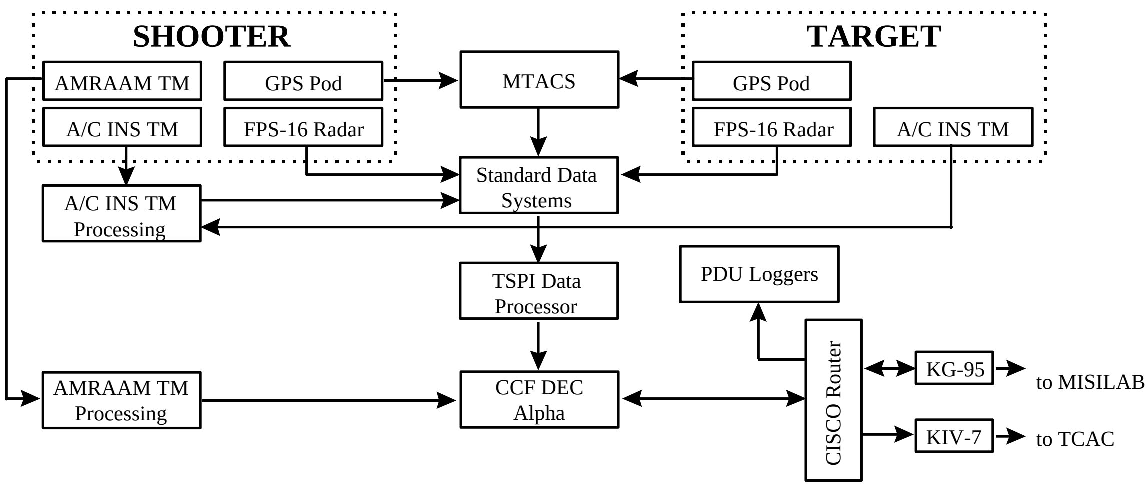


Figure 2.4.3.2-1. CCF Segment of LFP Processing and Data Flow.

The major features of Figure 2.4.3.2-1 are as follows:

- TSPI Data Processor (TDP)
  -- In order to provide highly accurate TSPI data, multiple sensors and extensive pre-processing were required. TSPI for each aircraft was generated by combining three sources:
    --- GPS pods provided accurate position data in the form of pseudorange measurements for each GPS satellite in view of the pod. The data were generated at a rate of 8 hertz (Hz) and were differentially corrected using the pseudorange

measurements from a ground reference receiver. GPS data were processed by the Multi-object Tracking and Control System (MTACS) before being input into the TDP.

--- INS data from the F-16 precision inertial sensor assembly provided accurate velocity, attitude, and attitude rate data at a rate of 50 Hz. Preprocessing of the INS data was required to remove time stamping inaccuracies (sampling jitter), thus lowering INS noise (error) before input into the TDP.

--- Ground-based tracking radars provided backup sources of position data. The FPS-16 radar provided azimuth, elevation, and range data at a rate of 10 Hz for both the shooter and target.

-- TSPI was incorporated into an optimal estimate using a TDP square root information filter (SRIF) process. The SRIF reduced sensor noise and provided the multi-sensor solution, which totally eliminated incoherent artifacts due to single instrument perturbations or datalink dropouts. A smoother algorithm was applied to the TDP solution before the data were incorporated into DIS 2.04-compliant Entity State (ES) PDUs. The TDP's filter output rate could vary between 10 and 30 Hz, but only operated reliably at 10 Hz.

- Telemetry Data Processing

-- Three serial pulse code modulation (PCM) telemetry data streams were radio frequency (RF) downlinked to the CCF:

--- The shooter and target aircraft PCM streams contained aircraft inertial data.

--- The AMRAAM ITV telemetry (TM) stream contained umbilical (launch) and targeting information. The AMRAAM ITV data was preprocessed and packed into DIS 2.04-compliant Data PDUs (only the header was DIS-compliant) for transmission to the MISILAB at a rate of approximately 104 Hz.

-- Filtering of the AMRAAM telemetry data was used to minimize the effects of data transmission errors (e.g., dropouts). The primary technique for filtering spurious data samples was monitoring the time stamps to determine if the time was progressing. Monitoring of condition codes and an internal asynchronous counter/timer provided a reliable indication that valid data were received.

- CCF Digital Equipment Corporation (DEC) Alpha

-- The DEC Alpha performed the following functions:

--- Captured TDP output and TM data and converted them into DIS 2.04-compliant PDUs. Performed necessary coordinate transformations for creating ES PDUs.

--- Merged and formatted the various data sources for transmission to the MISILAB and the TCAC via the router.

--- Controlled data input and output for the CCF.

--- Created parameters for control of MISILAB simulation.

- PDU Loggers

-- PDUs were logged on a Silicon Graphics, Inc. (SGI) Indigo 2, along with PDU statistics.

--- The logger could also be used for data replay.

-- PDUs were also logged on an SGI Indy, using JADS logger software.

- Cisco router was used to route the PDUs to the MISILAB and the TCAC

-- The PDU traffic was encrypted using a KG-95 encryptor before transmission to the MISILAB and a KIV-7 encryptor before transmission to the TCAC.

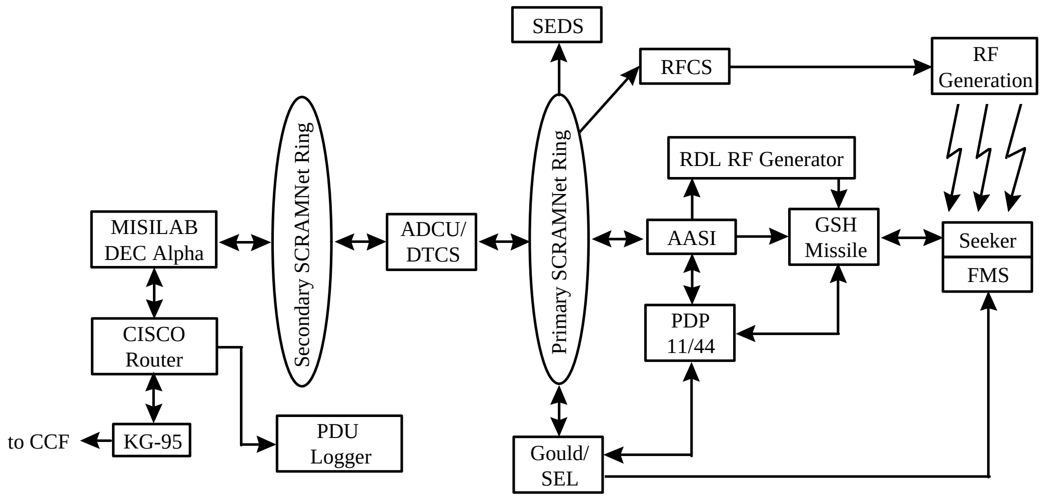


Figure 2.4.3.2-2. MISILAB Segment of LFP Processing and Data Flow.

The major features of Figure 2.4.3.2-2 are as follows:

- MISILAB DEC Alpha served as the interface between the CCF and the MISILAB and performed the following functions:
  - -- Performed coordinate transformations between ES PDU geocentric coordinates and MISILAB simulation local tangent plane (LTP) coordinates.
  - -- Converted DIS Data PDUs into format required by AASI.
  - -- Converted missile entity state data from the simulation into DIS ES PDUs.
  - -- Created DIS Fire and Detonation PDUs to indicate missile launch and detonation, respectively.
  - -- Interpolated the aircraft entity state data from the 10 Hz ES PDU rate to the 600 Hz rate required for input into the MISILAB simulation. The 10 Hz data from the ES PDUs were buffered and merged to ensure synchronization of the shooter and target data to each other before interpolation.
- Adaptive Data Collection Unit (ADCU) provided hardware for the Data Transfer and Capture System (DTCS). DTCS performed the following functions:
  - -- Handled the bi-directional data transfer between the MISILAB primary Shared Common Random Access Memory Network (SCRAMNet) ring (used in normal standalone operation) and the secondary SCRAMNet ring (added to allow data exchanges in ADS applications).
  - -- Captured target/shooter/missile entity state data for logging and provided Inter-Range Instrumentation Group -B (IRIG-B) time stamp. Data were logged at a rate of 100 Hz.
- Gould Systems Engineering Laboratory (SEL) 32/9780 was the master simulation control computer and performed the following functions:
  - -- Read shooter and target entity state data provided via the primary SCRAMNet ring.

- Monitored key event flags: umbilical separation and rocket motor fire.
- Computed missile dynamics and kinematics.
- Computed the seeker synthetic line-of-sight (SLOS).
- Output commands to control the Carco table holding the AMRAAM seeker.
- Controlled logging of simulation output (SEL data) at a logging rate of 10 Hz.
- Interfaced with analog computers which simulated aerodynamic control surfaces and control functions suitable to analog implementation.
  - Seeker commands which were intended for the missile's actuators were sent to the analog computers, which computed/predicted missile responses to these commands.
  - Responses were then sent to the Gould.
- Extrapolated missile flyout from the end of the MISILAB simulation (100 m range to target) to point of closest approach.

- AASI provided the link between the launch aircraft and the missile data processor and performed the following functions (see Appendix C, Annex 1 for AASI description):
  - Accepted umbilical and RDL information via SCRAMNet and reformatted the umbilical data as a launch message (target location, range, velocity, uncertainties, etc.) for the missile hardware.
  - Ensured that the government simulation hardware (GSH) missile (i.e., MISILAB missile) was initialized with the same launch message as the ITV missile.
    - The launch cycles of both the ITV and the GSH missiles were non-deterministic. The solution was to send recursive launch messages to the GSH missile to ensure the same message was used.
  - Synchronized transmission of the umbilical and rear data link (RDL) messages to the GSH missile with the shooter and target entity state data.
  - Controlled the RDL RF generator to ensure appropriate timing and frequency of the data link messages.
  - Logged all SCRAMNet traffic targeted for the AASI for subsequent use or playback.
- GSH missile consisted of actual AMRAAM hardware, missile RF data link receiver and processor hardware, and an inertial reference unit simulator. The GSH test station was controlled by a PDP 11/44 computer.
- The AMRAAM seeker was mounted on the flight motion simulator (FMS), a Carco table providing roll, pitch, and yaw degrees of freedom.
  - The FMS provided a prelaunch missile orientation calculated to matched that of the missile on the launch aircraft missile station. Pretable driver software on the Gould master computer ensured that the Carco table, and therefore the missile, was aligned with the shooter at time of pickle. To do this, table motion was initiated at least 10 seconds prior to pickle, and the table moved at a moderate fixed angular rate until aligned.
- Radio Frequency Control System (RFCS) controlled the RF scene viewed by the seeker. The RFCS was controlled by the Gould master computer.
- Simulation Engagement Display System (SEDS) provided a real-time, three-dimensional graphical representation of the simulated engagement between the missile and the target.
- PDU logger recorded PDUs on an SGI Indy using JADS logger software.

2.4.3.3 Test Control and Monitoring

There were four areas of test control: aircraft control, test control and monitoring, communications, and test procedures. The thrust of the test control investigation was to determine how much of the control function should reside at the individual nodes, how much needed to be at the central control node, and what communications were required between the nodes.

Aircraft control was exercised by air traffic controllers at the CCF. This function could not be exercised from the TCAC, due to range safety considerations. The test controller informed the air traffic controllers of the desired profile for each pass, and the air traffic controllers vectored the aircraft appropriately using two-way ultra high frequency (UHF) communications.

Overall test control was exercised from the CCF. The control center ensured that all players were ready for each run, issued the voice commands to start and stop the passes, and polled the players for quick-look results after each pass. The network controller in the TCAC coordinated all of the JADS logger personnel at the MISILAB, CCF, and TCAC via voice communications (using a conference telephone line).

The aircraft intercepts were monitored using two- and three-dimensional stealth viewers driven by entity state data. Quick-look results were available for the AMRAAM analysts at the MISILAB during the passes. The launch conditions were also displayed in the MISILAB immediately after each pass. Network performance was monitored during the trials at the TCAC.

2.4.3.4 Instrumentation

The same instrumentation will be used for all LFP missions at each site. Table 2.4.3.4-1 lists the instrumentation requirements. The data recorded on the instrumentation are identified in the LFP Integrated Data Requirements List.

Table 2.4.3.4-1. LFP Instrumentation Requirements.

Location	Description	Function
F-16C Shooter	IRIG-B time translator/generator	Test coordination
	HUD & VSD video camera & recorder	Capture aircraft displays
	Two RAJPO GPS pods	Capture & telemeter GPS
	ITV pod	AMRAAM missile surrogate
	C-band beacon	RF beacon for FPS-16 radar
F-16 Target	IRIG-B translator/generator	Test coordination
	HUD & VSD video camera & recorder	Capture aircraft displays
	Two RAJPO GPS pods	Capture & telemeter GPS
	C-band beacon	RF beacon for FPS-16 radar

Table 2.4.3.4-1. LFP Instrumentation Requirements (Concluded).

Location	Description	Function
CCF	IRIG-B time translator/generator	Test coordination
	4 mm tape recorder	Data transfer
	Loral 550	Process ITV TM
	Analog recorder	Record raw aircraft and ITV TM, radar data, and IRIG
	SGI Indy with JADS software	Record PDUs
	SGI Indigo 2 with STRICOM software	Record PDUs
	SNAP machine	Network analysis
MISILAB	IRIG-B time translator/generator	Test coordination
	DTCS logger	Record data passed into/out of simulation
	SEL logger	Record raw simulation data
	AASI logger	Record AASI data
	SEDS SGI 4D/3	Test monitor & trajectory plots
	Laser disk video recorder (& VHS dub)	Videotape of SEDS 3-D display
	Real-time chart recorders/displays	Test monitor
	SGI Indy with JADS software	Record PDUs
	SNAP machine	Network analysis
TCAC	SGI Indy with GPS receiver connection	Master time ref for loggers
	Three Barco 52” monitors	Flyout and data displays
	Stealth viewer	Test coordination
	SGI Indy with NetVisualyzer™ software	Network health data
	Video camera(s) & recorder(s)	Capture displays
	DIS data logger with JADS software	Record PDUs
	SGI Onyx RE2	3-D graphics viewer Metrica data server
	Sun 20 with SPECTRUM® software	Network statistics
	SNAP machine	Network analysis

2.4.3.5 PDU Logger Software

Two types of PDU logger software were used, as described below.

2.4.3.5.1 STRICOM DIS PDU Logger Software

This software was developed for the U.S. Army Simulation, Training, and Instrumentation Command (STRICOM) to evaluate applications for DIS compliance. The STRICOM PDU software provides a configuration, logging and display capability to record DIS PDUs, and a scanner capability to analyze the fields in the data records. For logger configuration, it has a network device display to select the network, protocol interface, data ports, etc. For logger control, the operator selects a filename and clicks on the recorder, pause, and stop buttons. The traffic monitor displays the total size and time of each file, and some statistics about incoming

PDU types (e.g., number of Entity State, Fire or Data PDUs, etc.). The scanner allows the analyst to view the data fields in the logger files; it's a tabular text display of the PDU number, time stamp, PDU type, entity identification (ID), etc. During the LFP tests, the STRICOM software was run on a SGI Indigo 2 computer in the CCF. The logged PDUs were used for replay of LFP runs.

2.4.3.5.2 JADS PDU Logger Software

JADS personnel developed a similar PDU logger to the STRICOM software above. This new logger software was named JADS PDU software version 1.0. It was modified from a DIS Training Institute (DISTI) program in order to log the PDUs faster with more accurate time stamping. It has similar configuration and recorder control functions, but does not display any incoming statistics on screen in order to keep the processing prioritized on the logging functions. This software was hosted on SGI Indy computers in the CCF, MISILAB, and TCAC. These logged PDUs were used primarily for analysis of LFP results.

2.4.3.6 Network Analysis Tools

2.4.3.6.1 Simulator Network Analysis Project (SNAP)

The SNAP systems collected data that were to be used to measure the latencies in the network, and specifically between nodes. The SNAP software was developed by the government at Wright-Patterson Air Force Base, Ohio, to evaluate simulation data. The JADS analysts used the SNAP software to record only the PDU headers with their timestamps in order to evaluate the latencies between the CCF, MISILAB, and TCAC. While the PDU loggers were used to measure the latencies for Entity State PDUs, the SNAP systems also measured the latencies on all the thousands of Data PDUs (which don't have entity IDs to distinguish their source location). The SNAPS were hosted on Pentium DX-100 computers at each facility.

2.4.3.6.2 NetVisualyzer™

NetVisualyzer™ is a collection of tools that collect data on the local Ethernet segments. Display and data stations were located in the TCAC, and data stations were hosted on the SGI Indy workstations placed at the simulation sites. The display station graphically displayed data collected from each data station on the network. NetLook (a tool in the display station) was used to monitor the health of critical nodes throughout the test. Also, the flow of network traffic between nodes was monitored. NetGraph displayed and recorded the bandwidth utilization (percentage of Ethernet capacity, packets/second, bytes/second, etc.) on the TCAC, CCF, and MISILAB local area networks. NetCollect was used at each data station site to record information about the protocols on each local area network (LAN) segment. NetAccount summarized the protocol data recorded by NetCollect. This gave information about the relative make-up of the protocol packets (the number and relative percentage by protocol type) seen on each LAN segment. NetSnoop was used to determine, in detail, what occurred on the network and recorded raw protocol data (in ASCII format). Since gigabytes of data can be logged quickly, this tool was not used throughout the entire test. Selected portions of the test, representative of the whole test, were used to record manageable amounts of data. The data collected were also used to troubleshoot problems.

2.4.3.6.3 SPECTRUM®

SPECTRUM® is a network management tool that uses Simple Network Management Protocol (SNMP) to look at various network nodes. The SNMP capabilities allowed monitoring of the routers to obtain information about traffic flows through them. This tool allowed measurement of bandwidth utilization on the wide area network (WAN) links (links between routers and LAN segments.)

2.4.3.6.4 Network General Sniffer

This tool provided diagnostic monitoring and troubleshooting capability. It examined the protocols on a single Ethernet segment (a LAN) and was used to monitor the traffic coming into the TCAC.

2.4.4 LFP Assumptions and Limitations

The following limitations apply:

- The profiles flown had restrictions due to the requirement for clean telemetry reception with minimal dropouts. These restrictions were as follows: on altitude, pass orientation, and range airspace.
    - Minimum altitude: The aircraft had to be flown above 21,000 ft when at a range of 35-45 miles offshore (the Gulf Test Range was used). This ensured a clear line-of-sight to the ground TM receivers and reduced the ground tracking radars elevation angle measurement errors (the tracking radars had reduced multipath effects when the aircraft were over 3.5° above their horizon).
    - Range airspace restrictions: The clear line-of-sight requirement above also required the aircraft to fly within 45 miles of the coastline (where the TM receivers were located). The best results were obtained when the aircraft were due south of the TM receivers.
    - Preferred pass orientations: East-west profiles (which paralleled the coastline) provided better TM reception than either north-south or diagonal profiles.
- The MISILAB used simple models for the RF scene background, such as glint, altitude return, clutter, and multipath effects.
- The missile HWIL laboratory was limited in the range of motion and could not handle large angles off and/or large angle rates. This limited scenario excursions.
- The LFP ADS configuration was a non-real-time system which precluded any investigations of closed-loop interactions between the missile and the target.
- ECM techniques involving synchronized ECM against both the shooter and the missile could not be implemented (i.e., only non-synchronized ECM techniques could be investigated).

3.0 Live Fly Phase Execution Results

This section describes mission rehearsal and execution activities with emphasis on the deviation from the planned test approach.

3.1 Risk Reduction Efforts

3.1.1 Risk Reduction Plan

The objective of risk reduction (RR) tests RR#0 through RR#7 was to prepare in a methodical manner for the first actual live flight mission. The risk reduction suite of tests were originally designed as pretest set up, calibration, and check out of the live fly phase (LFP) architecture. The events were broken down into discrete segments which would allow for verification of specific areas of the architecture before committing to the use of live assets. Procurement delays with the Advanced Aircraft Simulation Interface (AASI) caused some schedule slips in the planned events. Additional delays were caused by scheduling conflicts with higher priority test programs at Eglin AFB. The System Integration test (SIT) team further modified the original risk reduction plan as the result of lessons learned from the linked simulator phase (LSP) advanced distributed simulation (ADS) test which was completed at the Naval Air Warfare Center Weapons Division (NAWCWPNS), China Lake, California, in late 1996.

3.1.2 Risk Reduction Detailed Schedule

The following top level task in Figure 3.1.2-1 describes the original plan for the LFP risk reduction effort.

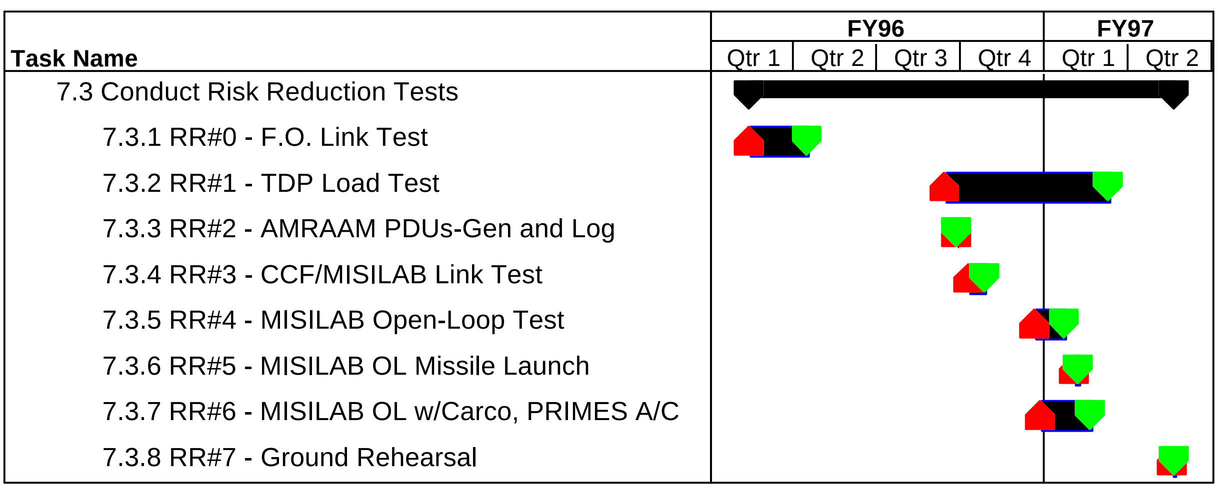


Figure 3.1.2-1. Original Planned Risk Reduction Schedule.

- RR #0 - Fiber Optic Link Test: Verify physical paths of data transfer between Preflight Integration of Munitions and Electronics Systems (PRIMES), Central Control Facility (CCF), Missile Simulation Laboratory (MISILAB) and Test Control and Analysis Center (TCAC). Simulation of radar telemetry (TM) from PRIMES for input to the time-space-position information (TSPI) Data Optimizing Processor (TDP) for producing Entity State (ES) protocol data units (PDUs).

- RR#1 - TDP Load Test: Load test of the TDP using PRIMES as a source for TSPI data. PRIMES using 6-DOF (degree of freedom) program to control 4 global positioning system (GPS) pods and generate simulated tracking radar and aircraft inertial navigation system (INS) data streams.

- RR#2 - AMRAAM PDUs-Generate and Log: Convert advanced medium range air-to-air missile (AMRAAM) data from previously logged mission into distributed interactive simulation (DIS) compliant PDUs and log the PDUs with the U.S. Army Simulation, Training and Instrumentation Command (STRICOM) data logger.

- RR#3 - CCF/MISILAB Link Test: Transfer TSPI and AMRAAM PDUs from CCF to MISILAB Alpha computer in real time using encryption. Verify record and playback capability of the MISILAB Alpha computer.

- RR#4 - MISILAB Open-Loop Test: Provide either live data from CCF or previously recorded data to generate radio frequency (RF) scene and drive the Carco table in MISILAB.

- RR#5 - MISILAB Open-Loop Missile Launch: Drive Carco table and generate RF scene in MISILAB with live or recorded data. Verify RF scene generated using seeker data from captive missile launch in visual mode.

- RR#6 - MISILAB Open-Loop with Carco, PRIMES Aircraft: Drive Carco table and generate RF scene in MISILAB using PRIMES data via CCF. Obtain data and evaluate suitability for AASI testing.

- RR#7 - Ground Rehearsal: Launch missile, drive flight motion simulator (FMS), and generate RF scene in MISILAB using PRIMES data via CCF. Verify AASI performance, as well as generate miss distance.

3.1.3 Risk Reduction Results

The results of the risk reduction tests are discussed in this section. Figure 3.1.3.1-1 is provided to compare the actual event dates to the original schedule. RR#1 through RR#5 are discussed together and RR#6 through RR#10 are addressed individually.

3.1.3.1 Risk Reduction Tests #0-#5

RR#0 through RR#5, as described in Section 3.1.2, were designed as individual integration efforts for specific portions of the LFP ADS architecture. These efforts were developmental in nature and were designed to verify the ability of key hardware and software to support the capture, use, and distribution of data. This data path included the CCF data collection of TSPI and integration test vehicle (ITV) telemetry, TDP processing, and transmission to the MISILAB. The ultimate purpose of this data flow was to drive the Carco table in response to an RF scene which faithfully represented TSPI inputs.

RR#0 and RR#2 through RR#5 were successfully conducted with only minor problems. Comparing Figure 3.1.3.1-1 with Figure 3.1.2-1 shows the schedule slips over the planned events. Although several of the test dates slipped, the largest contributor to the overall delay was RR#1. RR#1, the TDP Load Test, was originally designed as a piggyback on a live flight mission on the Eglin range. Numerous efforts were planned as piggyback missions, but none were flown because of security issues.

Because funding constraints precluded flying dedicated missions for TDP testing, the SIT team was forced to rely on simulated TDP inputs from the PRIMES facility. The PRIMES approach was subject to some limitations which are discussed in Section 3.1.3.2.

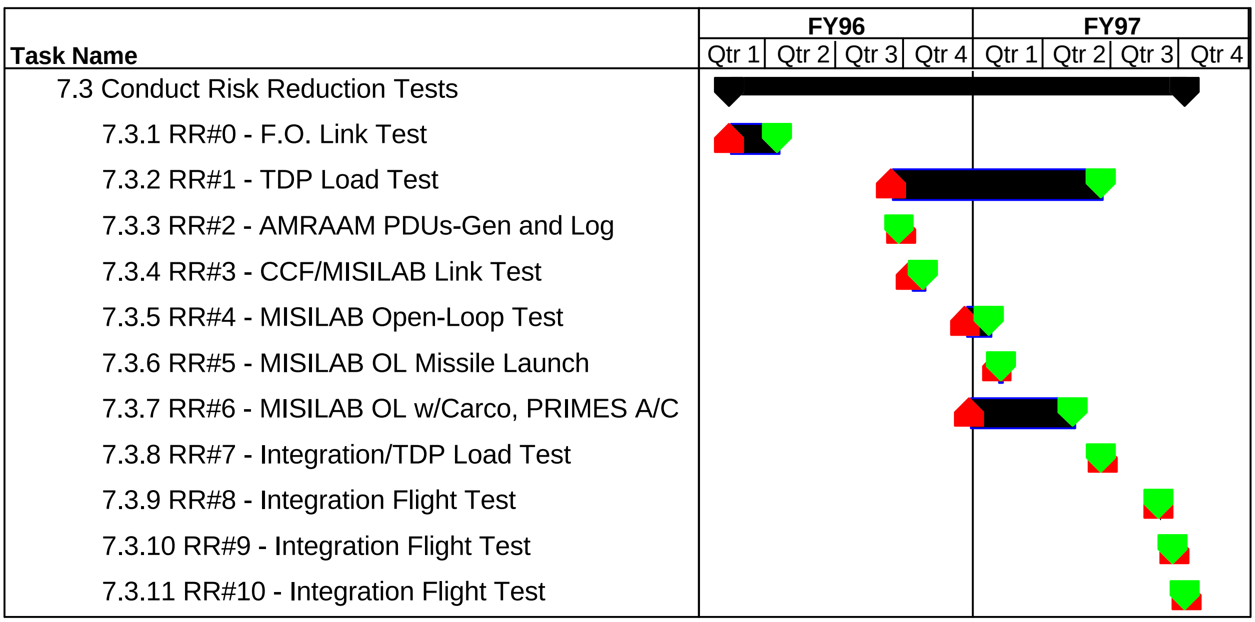


Figure 3.1.3.1-1. Actual Risk Reduction Schedule.

3.1.3.2 Risk Reduction Test # 6

The objective of RR#6 was to use PRIMES inputs to successfully drive the Carco table, generate the RF scene based on TSPI data, complete a manual launch, and perform a top-down analysis in the MISILAB. This risk reduction effort suffered the largest schedule slip of the seven originally scheduled events. The intent was to use inputs which would be no different than actual flight data. If this had been successful, the LFP schedule could have gone directly from RR#6 to live testing. Several significant technical issues prevented the SIT team from executing the original plan.

The first two attempts at RR#6 (21-22 November 1996 and 11 February 1997) were unsuccessful. The major technical problem for both attempts was the inability to provide GPS satellite ephemeris data to the input of the TDP. The ephemeris data were required to allow proper satellite orbit modeling by the TDP. The inability to provide these data was a simulation limitation of the PRIMES that was not fully understood when RR#6 was originally planned. This lack of valid GPS data forced the TDP to calculate a position solution based only on the INS and radar inputs from the PRIMES facility. The impact of this limitation was compounded by the inability to complete the full TDP load test (RR#1) with live piggyback data. At the conclusion of RR#6, the TDP was still not fully load tested with all the required inputs. The next scheduled event was RR#7 which would use the same PRIMES inputs as RR#6.

The SIT team determined that this configuration offered excessive risk to the LFP test, and as a result, the remaining testing was restructured to allow for a valid test of the TDP prior to formal flight testing. The restructuring changed RR#7 from a ground rehearsal using PRIMES inputs to an actual flight test to provide all required inputs to the TDP. RR#8 through RR#10 were added as live flights to allow for a complete check out of the LFP ADS architecture and test procedures prior to Mission #1. Cost and schedule considerations influenced the shift to the use of live aircraft instead of correcting the limitations with the PRIMES setup. The cost of a full-up PRIMES mission was only slightly less than flying actual aircraft (see Section 4.5.1.3). Even if the PRIMES limitations were corrected, an actual flight test would still have been required to verify the overall architecture prior to Mission #1.

3.1.3.3 Risk Reduction Test #7 (As Restructured)

RR#7 was conducted on 21 March 1997. This event was the first test in which both target and shooter aircraft were used in a live flight test. The test produced aircraft entity state and data PDUs and drove the Carco table in the MISILAB. The mission log for this test is shown in Table 3.1.3.3-1 at the end of Section 3. Several significant deficiencies and their causes were identified with the data collected.

- A launch synchronization issue was identified between the ITV data and TSPI data. The Hughes AASI experts determined that the original AASI software pickled the missile when it received the launch message from the ITV. The ITV data PDUs were generated as they were received but the entity state PDUs were subject to processing delays of more than two seconds. As a result, the AASI would launch the missile at a target which was located more than two seconds behind the target location in the ITV message. Hughes determined that a software change was needed to delay the AASI umbilical message until the TSPI data with the same IRIG time were received in the MISILAB. When the TSPI time was equal to or greater than the launch message, the AASI would start the launch sequence.

- The MISILAB noticed large gaps in the aircraft entity state data (1-4 seconds). The gaps were due to either telemetry or INS dropouts from the shooter. Dropouts of telemetry appeared to be related to shielding by the two external fuel tanks carried on the aircraft wings. After consulting with Eglin test engineers, it was decided that future flights would use a single external centerline fuel tank to prevent shielding of the telemetry data. The INS dropouts seemed to be a function of an INS clock problem on the aircraft itself. Post-mission troubleshooting on the target aircraft confirmed the problem, and a maintenance writeup was submitted for the aircraft.

- The TDP experienced occasional input rejections, and the solution exhibited spotty data output rates. This problem was blamed on the erratic behavior of the INS data.

Although there were major problems during RR#7, the test was a considered a success for a risk reduction effort. The test led to the identification and correction of several significant technical problems.

3.1.3.4 Risk Reduction Test #8

RR#8 was conducted on 5 June 1997 with poor results. This flight test was conducted to verify hardware and software corrections that were implemented after RR#7. The mission log for this test is shown in Table 3.1.3.4-1 at the end of Section 3. Only 4 of 16 passes attempted produced usable data. Several of the problems appeared to be similar to those seen in RR#7.

- The majority of runs experienced ITV data dropouts. RR#7 identified telemetry shielding from the two outboard external fuel tanks, so RR#8 was run with a single centerline fuel tank. Additional discussions with the Eglin test engineers uncovered the fact that telemetry shielding would occur when <u>any</u> external fuel tanks were used. It was decided that all future flights would be flown without external tanks, and additional fuel would be obtained from airborne tankers. The shielding issue was compounded by operating in the extreme eastern boundaries of the test range. The quality of telemetry was improved when the aircraft were closer to the shore receiver sites.

- Real data link (RDL) messages were lagging the target location between 0.3 and 1.5 seconds on some passes. Several other passes did have properly synchronized RDL messages. The loss of synchronization was tracked to the production of spurious RDL data. Invalid, or noise, RDL messages were generated when certain telemetry conditionals were "true." During flight test, the "true" state was sometimes satisfied by "noisy" telemetry. Once the cause had been determined, code changes were made to the software that generated the data PDUs containing the RDL data. Lab testing confirmed the correction was effective in eliminating the bad RDL messages.

- The Multi-object Tracking and Control System (MTACS) processing system was unable to handle the data from four GPS pods. Diagnostics confirmed that with four pods buffers were backing up, and data were being lost. The original design of the TDP called for the input of two GPS pods per aircraft operating in the raw receiver mode. The two pods were to provide for a more accurate positional solution and for added reliability. Since the MTACS system could not handle the required data flow, the Eglin TDP and MTACS experts decided that future missions should be run with one pod in the raw receiver mode and the other pod on that aircraft operating in the navigation solution mode. In addition, if the aircraft INS failed, the navigation solution would provide velocity data that normally were provided by INS.

- INS on the target aircraft experienced a failure. The microsecond clock on the aircraft was frozen, preventing any valid INS information from being generated. Post-mission troubleshooting on the target aircraft confirmed the problem, and a maintenance write-up was submitted for the aircraft.

3.1.3.5 Risk Reduction Test #9

RR#9 was conducted on 24 June 1997 with very poor results. This flight test was conducted to verify hardware and software corrections that were implemented after RR#8. The mission log for this test is shown in Table 3.1.3.5-1 at the end of Section 3. None of the 16 runs produced valid RDL messages. One new problem was experienced, but there appeared to be repeat problems seen in previous testing.

- The target INS microsecond clock malfunctioned. This aircraft was the same one used during RR#8. The clock failed in a slightly different manner than in RR#8. The microsecond clock would output a single valid time, freeze for 59 seconds, and then repeat the cycle. Each cycle had a single valid time with a 59 second pause. Post-mission troubleshooting on the target aircraft confirmed the problem. In addition to repairing the aircraft, an additional monitoring capability was implemented to verify the INS clock function before takeoff on future flights.

- No GPS data was successfully used during any of the passes. The MTACS system was unable to handle the data from four GPS pods. Data confirmed that with four pods the buffers were backing up, and data were being lost. RR#9 was conducted with the pods split (one in raw receiver mode, the other in navigation solution mode). The data rate with the split mode should have been lower than for the original two pod raw receiver setup. The original design of the TDP called for the input of two GPS pods per aircraft operating in the 8 Hz raw receiver mode. Since the MTACS could not handle the required data flow even in a lower rate setup, the Eglin TDP and MTACS experts decided that future missions should be run with one pod per aircraft operating in the raw receiver mode and one pod in a non-transmitting standby mode.

3.1.3.6 Risk Reduction Test #10

RR#10 was conducted on 11 July 1997. The mission log for this test is shown in Table 3.1.3.6-1 at the end of Section 3. The mission was considered a success with 12 of 20 attempted passes satisfactory. Overall performance of the LFP architecture was much improved with only a few problems.

- Target INS data were missing from the first 12 runs. The loss of INS data was due to ground-based telemetry processing systems and not the aircraft. The malfunctioning hardware was located and switched, thereby restoring INS data for passes #12 through #20.

- RDL synchronization was achieved with excellent results. The target location from the RDL message usually agreed with that from the entity state data to within 30 meters.

- The TDP appeared to operate as advertised without crashes or reboots for more than two hours. One of the GPS pods failed in flight and was shut down. The standby pod was brought into operation and provided valid GPS data for the remainder of the flight.

- Range radar for the target failed during the mission, and a change to a different pad failed to solve the problem. The original radar pad was successfully reselected, and it provided valid data for the remainder of the mission.

3.2 Flight Missions Detailed Schedule

The original LFP schedule called for three live flight tests which are shown in Figure 3.2-1, and the actual schedule is shown in Figure 3.2-2.

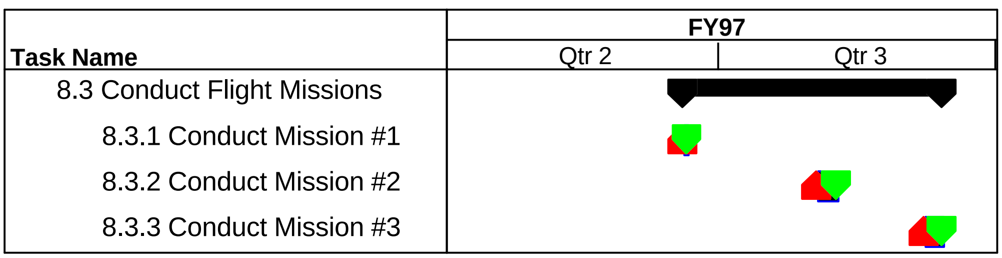


Figure 3.2-1. Planned Flight Mission Schedule.

The original mission objectives were as follows:

- Mission #1 : Primary objective was to check out and verify performance of all subsystems as well as the overall LFP ADS configuration.
- Mission #2 : Primary objective was to provide validation data for both the OP-612 and OP-617 scenarios.
- Mission #3 : This mission was designed to investigate variations on the primary OP-612 scenario by using three different fire control radar modes.

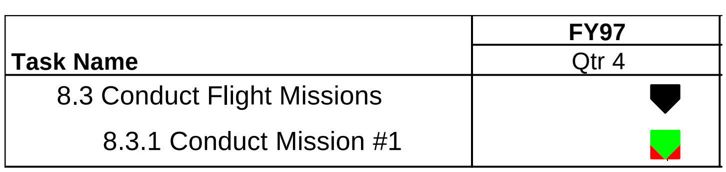


Figure 3.2-2. Actual Flight Mission Schedule.

The objective for the actual Mission #1 was to fly the OP-612 and OP-617 profiles in order to collect sufficient data for use in validation analysis and Monte Carlo runs. The majority of fixes for problems identified in RR#7 through RR#10 had been verified in playback testing prior to the mission.

3.2.1 Mission #1 Execution

Mission #1 was conducted on 11 September 1997. The mission log for this test is shown in Table 3.2.1-1 at the end of Section 3. The mission was considered a success with 14 of 17 passes producing complete missile flyouts. All objectives for the mission were met with only minor problems encountered.

- The MTACS processing system was unable to send ephemeris data for two satellites from the GPS pods to the TDP. This caused the TDP to produce positional solutions based on three or four satellites, instead of the normal five. This lack of data resulted in a minor degradation in accuracy on some of the runs.

- Three of the 17 passes were aborted due to a loss of synchronization caused by telemetry dropouts. A lost synchronization abort occurred when the shooter and target ES PDUs had a relative latency of greater than 500 ms. The elastic buffer in the MISILAB detected the excessive time difference between PDUs and sent a warning message. When a warning message was received, the MISILAB was notified, and the hardware-in-the-loop (HWIL) was stopped to prevent possible damage to the missile from violent maneuvers. The telemetry loss resulted when the aircraft were moved to the far boundaries of the test area for refueling. As the aircraft moved back closer to the ground receiver, the telemetry dropouts cleared up.

Mission #1 provided sufficient data to satisfy the objectives of the originally planned Missions #2 and #3. RR#10 had satisfied the objectives of the original Mission #1. With the LFP test objectives being met, the SIT team canceled the remaining flights and proceeded directly to the Monte Carlo replays.

3.3 Monte Carlo Replays

Monte Carlo runs were planned as part of the LFP verification and validation (V&V) effort under test objective 1. The Monte Carlo runs involved replaying recorded flight data into the MISILAB. The selection and purpose of these runs is discussed further in Section 4.1.2.1. The original LFP schedule called for the Monte Carlo runs to be conducted on 11 July 1997, and they were actually performed on 29-30 October 1997. Four flyouts from Mission #1, as well as the original data from OP-612, were selected for replay with a minimum goal of 25 runs of each. Some minor problems were encountered during the replays, and a total of 228 runs were attempted to obtain the 150 runs required for validation analysis. (25 valid runs were required for each run set.)

The six Monte Carlo run sets were as follows:

1. Original aircraft data from the actual OP-612 profile from Jun 94
2. Best modified OP-612 linked run from Mission #1 (fire control radar [FCR] in track-while-scan [TWS])
3. Best modified OP-612 linked run from Mission #1 (FCR in single target track [STT])
4. Best modified OP-617 linked run from Mission #1
5. Anomalous modified OP-617 linked run from Mission #1
6. Best modified OP-617 linked run from Mission #1 replayed from analog tapes in the CCF though the TDP (in order to generate a new TDP solution each run)

4.6 Analysis Summary

Test Objective 1: Assess the validity of advanced medium range air-to-air missile (AMRAAM) data obtained in the life fly phase (LFP) advanced distributed simulation (ADS) configuration

- Verification
  - -- The facilities were properly linked.
    - --- The missile in the Missile Simulation Laboratory (MISILAB) hardware-in-the-loop (HWIL) facility responded correctly to the inputs received. The missile seeker acquired, tracked, and guided to the target.
  - -- There were no errors in transforming entity state data.
  - -- There were no protocol data units (PDU) transmission errors.
  - -- The time-space-position information (TSPI) Data Processor (TDP) operated properly: Invalid inputs were rejected from the solution.
  - -- The Advanced Aircraft Simulation Interface (AASI) operated properly: The AASI was able to synchronize the umbilical message to the shooter and target entity state data, and the synchronization value reported by the AASI on each run was valid.

- Validation
  - -- The MISILAB stand-alone simulations of the OP-612 engagement were valid. This reaffirmed the expectation that the MISILAB HWIL simulation in a stand-alone configuration would provide valid AMRAAM results.
    - --- Apparent errors in the OP-612 TSPI data, along with the unlikelihood of replicating the umbilical and data link messages, required that comparisons of the LFP replications of OP-612 to the actual OP-612 involve qualitative comparisons of missile telemetry data only.
  - -- The validation process compared the missile performance results of a single linked run to the envelope of 25 MISILAB stand-alone runs which all used the same launch conditions, umbilical and data link messages, and target trajectory as the linked runs. Four linked runs were selected for validation.
  - -- The validation process was applied to the following MISILAB output parameters:
    - --- Missile trajectory.
    - --- Missile telemetry signals.
      - ---- Missile-to-target range and range rate versus time.
      - ---- Missile seeker azimuth and elevation angles versus time.
      - ---- Missile orientation (roll, pitch, yaw) versus time.
    - --- Missile timelines.
  - -- The validation process revealed the following:
    - --- The MISILAB HWIL facility provided proper and valid responses to its inputs. All of the MISILAB output parameters evaluated were assessed to be valid.
    - --- The umbilical and rear data link (RDL) data provided to the HWIL facility agreed in content and timing with data transferred between the shooter aircraft and the integration test vehicle (ITV) 98% of the time.

    --- The tracking errors from the umbilical and RDL data agreed with the known F-16 fire control radar (FCR) errors.
    --- AMRAAM data from the LFP ADS configuration exhibited similar properties as those observed in actual AMRAAM flight tests. Through qualitative analysis, the reasonableness of LFP data, as compared to actual AMRAAM flight test data, was determined.
  -- Results of the verification and validation analyses support the conclusion that the LFP ADS configuration provided valid AMRAAM data and a valid testing environment for an integrated launch aircraft/missile weapon system.

Test Objective 2: Assess ability of LFP ADS configuration to perform AMRAAM testing

- The LFP ADS configuration would be able to accomplish some live AMRAAM testing objectives, within certain limitations.
- The limitations reduce the variety of scenarios which could be evaluated. However, these limitations were due to the range and facilities used, as well as the ADS implementation.
- For those AMRAAM test objectives and scenarios for which the LFP ADS configuration could be used, there are advantages to using the ADS configuration.
  -- Quick-look results would be available immediately after each pass.
  -- Highly accurate TSPI data would be used to drive the AMRAAM HWIL simulation.
  -- The analyst-in-the-loop would ensure efficient use of live range time.
  -- Live fire missile tests could be effectively rehearsed.

Test Subobjective 3-1: Assess ability to provide required TSPI accuracy

- The TDP solution met the MISILAB accuracy requirements of 5 m in position and 1m/s in velocity whenever relatively accurate aircraft INS data were input to the TDP.
- The TDP output did not appear to meet the MISILAB attitude accuracy requirement of 0.2°, as implied by the amount of smoothing of the data.
  -- This requirement was overly stringent, and the attitude accuracy achieved was not expected to affect the validity of the MISILAB results.
- The accuracy of the TDP solution for attitude rates could not be estimated.
- Smoothing of the TDP solution did not degrade the accuracy of the position or velocity data.
- The TDP solution accuracy was much better than can be achieved with standard range TSPI systems during live fire missile tests.

Test Subobjective 3-2: Assess ability to provide required reference frame alignment accuracy

- The shooter and target entity state data were correctly converted from the TDP reference frame to the entity state (ES) PDU reference frame and then to the MISILAB reference frame.
- The position of the missile was correctly aligned to the shooter location prior to launch.

- The missile entity state data were correctly converted from the MISILAB reference frame to the ES PDU reference frame.

Test Subobjective 3-3: Assess ability to provide required data synchronization

- The shooter and target entity state data were synchronized to each other for input into the MISILAB simulation to within the accuracy of the entity state data time tag, ±2 millisecond (ms).
- There was a steady loss of synchronization of the aircraft entity state data input into the simulation relative to elapsed real time.
  - The net loss of synchronization was only about 5 ms by the end of a run and resulted in an insignificant target position offset (~1.4 meter [m]).
- The umbilical and RDL messages were synchronized to the entity state data to within about 20 ms.
  - This could result in an insignificant difference between the target position indicated in an umbilical/RDL message and that from the entity state data (~5 m).
- The required degree of data synchronization was achieved.

Test Subobjective 3-4: Identify and quantify latency of LFP ADS configuration

- The latencies during Mission #1 were relatively stable and consistent, but fairly large.
  - The total latency of the MISILAB simulation was about 3.1 seconds.
- The largest contributor to the total latency (~ 2.5 s) was the TDP processing and smoothing of the aircraft entity state data.
- The other major source of latency (~600 ms) was the buffering of the aircraft entity state data needed for synchronization of the MISILAB simulation inputs.
- Transmission delays made an insignificant contribution to the total latency.

Test Subobjective 4-1: Assess capability of ADS network to provide bandwidth and connectivity required for LFP tests

- The maximum bandwidth utilization was low on both the T3 linking the Central Control Facility (CCF) and the MISILAB (<1%) and the T1 linking the CCF and the Test Control and Analysis Center (TCAC) (<3%).
- There was no loss of connectivity during the LFP missions.

Test Subobjective 4-2: Assess the effects of ADS-induced errors on LFP test results validity

- No significant ADS-induced errors were found.

Test Subobjective 4-3: Assess adequacy of DIS protocol data units for LFP test

- The DIS PDUs used in the LFP were adequate for the required data exchanges.
  - The use of PDUs did not result in bandwidth utilization problems.
  - There were no coordinate transformation errors associated with the use of ES PDUs.

  - -- The use of Data PDUs did not corrupt the AMRAAM telemetry data sent to the MISILAB.

Test Subobjective 4-4: Assess reliability, availability, and maintainability of ADS network

- There was no network down time during risk reduction (RR) #10 and Mission #1: the availability of the ADS network was 100%.
- There were three hardware failures, and the average time for repairing them was 34 min.
- There were no software faults during RR#10 and Mission #1.

Test Subobjective 4-5: Assess capability to remotely control and monitor test

- The test control procedures worked well, in general.
- Centralized test control had to be exercised from test range (CCF).
  - -- Range safety policy required local control of live aircraft.
- Situational awareness of the Joint Advanced Distributed Simulation (JADS) test director needed to be better.
  - -- Better communications needed.

Test Subobjective 5-1: Document programmatic costs for the SIT LFP

- Categorized cost data were captured and showed the following:
  - -- The total cost of the LFP was about $4.1M.
  - -- The portion of the total cost for test bed preparations and equipment purchases was about $2.6M.
  - -- The portion of the total cost for integration was about $1M.
  - -- The portion of the total cost for test execution was about $500K.
- Typically, a two-hour live flight mission cost between $54K and $57K with an average cost of about $3.2K per pass.
- The average cost of performing the Monte Carlo validation runs was about $8.3K for each linked pass or profile selected for validation.

Test Subobjective 5-2: Document test procedures for the SIT LFP

- The following was documented:
  - -- Operator checklists.
  - -- Procedures for planning and scheduling live aircraft, range assets, and supporting facilities.

5.0 Live Fly Phase Lessons Learned

In order to successfully integrate the various assets for a near real-time test, the System Integration Test (SIT) team learned several lessons during the planning, integration, and test execution phases. The lessons are broken down into two main categories of technical lessons learned and infrastructure lessons learned. These main categories are further broken down as follows:

- Technical Lessons Learned
  - Simulations
  - Interfaces
  - Networks
  - Instrumentation
  - Data processing

- Infrastructure Lessons Learned
  - Procedures
    - Lessons during planning phase
    - Lessons during development phase
    - Lessons during execution phase
  - Policy
  - Costs
  - Personnel

5.1 Technical Lessons Learned

5.1.1 Simulations

- <u>Stand-alone simulation facilities can require significant modifications before effective linking is possible</u>. The linked configuration of the Eglin Preflight Integration of Munitions and Electronics Systems (PRIMES) facility to the Central Control Facility (CCF) was not adequate to accomplish the ground rehearsal objectives. PRIMES is a very good installed system test facility (ISTF) when used in stand-alone mode, but there were some software interface problems in the advanced distributed simulation (ADS) - linked configuration. Specifically, the simulated time-space-position information (TSPI) inputs were not adequate to properly load the TSPI Data Processor (TDP), which necessitated the use of live aircraft for future integration missions.
  - Inputs from the three TSPI sources (global positioning system [GPS], inertial navigation system [INS], and range tracking radar) were to be received and preprocessed in the CCF, then combined in the TDP. However, the simulated GPS data were either rejected or had large residual errors. The simulated GPS configuration also could not provide differential corrections, nor use the real-time satellite ephemeris data; therefore, only the pre-recorded raw GPS measurements from almanac data were used for a GPS solution, and this was inadequate.

-- Although the vast majority of linking issues, data formats and aircraft connections are fully developed, a few TSPI interface problems need to be resolved between PRIMES and the CCF. Then, this can provide a valid and useful ISTF to hardware-in-the-loop (HWIL) simulation.

5.1.2 Interfaces

- <u>Linking may require special purpose interfaces</u>**.** Simulations which normally run stand alone may require special purpose interfaces to accept inputs in real time, and development of such units must be factored into test planning.

-- The LFP ADS configuration required such an interface (the Advanced Aircraft Simulation Interface [AASI] The major features of Figure 2.4.3.2-1 are as follows:

- TSPI Data Processor (TDP)
  - -- In order to provide highly accurate TSPI data, multiple sensors and extensive pre-processing were required. TSPI for each aircraft was generated by combining three sources:
    - --- GPS pods provided accurate position data in the form of pseudorange measurements for each GPS satellite in view of the pod. The data were generated at a rate of 8 hertz (Hz) and were differentially corrected using the pseudorange measurements from a ground reference receiver. GPS data were processed by the Multi-object Tracking and Control System (MTACS) before being input into the TDP.
    - --- INS data from the F-16 precision inertial sensor assembly provided accurate velocity, attitude, and attitude rate data at a rate of 50 Hz. Preprocessing of the INS data was required to remove time stamping inaccuracies (sampling jitter), thus lowering INS noise (error) before input into the TDP.
    - --- Ground-based tracking radars provided backup sources of position data. The FPS-16 radar provided azimuth, elevation, and range data at a rate of 10 Hz for both the shooter and target.
  - -- TSPI was incorporated into an optimal estimate using a TDP square root information filter (SRIF) process. The SRIF reduced sensor noise and provided the multi-sensor solution, which totally eliminated incoherent artifacts due to single instrument perturbations or datalink dropouts. A smoother algorithm was applied to the TDP solution before the data were incorporated into DIS 2.04-compliant Entity State (ES) protocol data units (PDUs). The TDP's filter output rate could vary between 10 and 30 Hz, but only operated reliably at 10 Hz.
- Telemetry Data Processing
  - -- Three serial pulse code modulation (PCM) telemetry data streams were radio frequency (RF) downlinked to the CCF:
    - --- The shooter and target aircraft PCM streams contained aircraft inertial data.
    - --- The advanced medium range air-to-air missile (AMRAAM) integration test vehicle (ITV) telemetry (TM) stream contained umbilical (launch) and targeting information. The AMRAAM ITV data was preprocessed and packed into distributed simulation (DIS) 2.04-compliant Data PDUs (only the header was DIS-

compliant) for transmission to the Missile Simulation Laboratory (MISILAB) at a rate of approximately 104 Hz.

-- Filtering of the AMRAAM telemetry data was used to minimize the effects of data transmission errors (e.g., dropouts). The primary technique for filtering spurious data samples was monitoring the time stamps to determine if the time was progressing. Monitoring of condition codes and an internal asynchronous counter/timer provided a reliable indication that valid data were received.

- CCF Digital Equipment Corporation (DEC) Alpha
  -- The DEC Alpha performed the following functions:
    --- Captured TDP output and TM data and converted them into DIS 2.04-compliant PDUs. Performed necessary coordinate transformations for creating ES PDUs.
    --- Merged and formatted the various data sources for transmission to the MISILAB and the Test Control and Analysis Center (TCAC) via the router.
    --- Controlled data input and output for the CCF.
    --- Created parameters for control of MISILAB simulation.
- PDU Loggers
  -- PDUs were logged on a Silicon Graphics, Inc. (SGI) Indigo 2, along with PDU statistics.
    --- The logger could also be used for data replay.
  -- PDUs were also logged on an SGI Indy, using Joint Advanced Distributed Simulation (JADS) logger software.
- Cisco router was used to route the PDUs to the MISILAB and the TCAC
  -- The PDU traffic was encrypted using a KG-95 encryptor before transmission to the MISILAB and a KIV-7 encryptor before transmission to the TCAC to link the shooter aircraft-generated targeting messages to the HWIL missile in real time. Development of this unique asset had not been anticipated during the test concept development phase of the LFP. As a result, contracting and development lead times, along with developer priorities, resulted in causing a slip in the LFP schedule of over a year.

- <u>Key interfaces need realistic integration testing</u>. Realistic integration testing was performed by either replaying data recorded from live missions or by conducting an actual live mission.
  -- Because it was cost effective, integration testing was performed by replaying data whenever possible.
    --- This approach was successful in testing the interface between the CCF and the MISILAB and the interface between the AASI and the HWIL missile.
  -- Some integration testing required a live mission.
    --- Replaying data could not be used for the TDP load test or the mission rehearsal, because recorded GPS data could not be replayed and synchronized to the other TDP inputs. For this reason, the PRIMES was to be used to generate live data inputs for the TDP. Unfortunately, the PRIMES was unable to generate valid GPS data, and it was necessary to use live aircraft and live TSPI sources to successfully check out the CCF and TDP processing.
    --- Telemetry systems needed to be tested using actual mission profiles and aircraft in order to test for dropout conditions and to minimize dropouts.

5.1.3 Networks

- Early definition of network requirements was very advantageous. Having accurate requirements for network connectivity identified early in the program was very advantageous for linking the distributed facilities. JADS network experts estimated the necessary data throughput, encryption, and storage requirements for the ADS network. Their accuracy and resourcefulness allowed them to choose between a few hardware and firmware alternatives, and their early decision making allowed enough time to acquire the right components through government channels and contracts for the commercial data circuits. This early planning allowed early network integration testing, well ahead of other facility checkouts.

- The T1 link to the TCAC was excellent for data transfer. Since JADS data analysis was performed in the TCAC, it was extremely useful to have a T1 data circuit for transferring all of the range data from the CCF to the TCAC within a day or two after the missions. The JADS personnel had to coordinate directly with the owners of each data set to have them download their files onto a specific computer directory at Eglin, and some files required some post-processing to convert them to a standard data format. After logging into the computer directory, personnel from either the TCAC or Eglin could easily transfer large classified files over the encrypted T1 circuit to the TCAC via the file transfer protocol (FTP) utility. This ease of transfer allowed analysis to start very soon after each mission.

5.1.4 Instrumentation

- Changes and upgrades to aircraft instrumentation delayed development. Specially instrumented aircraft were required to support the LFP test flights. Due to the small number of such aircraft, the LFP schedule was very sensitive to periodic aircraft phase inspections, software upgrades, and higher priority missions.
  - The Eglin team had developed some ADS software based on using Programmable Data Acquisition System (PDAS) instrumentation. However, after 10 months of development, those PDAS-equipped F-16 aircraft became unavailable to the LFP due to unforeseen long-term commitments. The Eglin programmers were then forced to modify the LFP ADS software to accept some different instrumentation, called Advanced Airborne Test Instrumentation Systems (AATIS). This change took about 6 weeks to complete, and caused the LFP to switch to three other aircraft.
  - Another change occurred midstream with the GPS pods being upgraded from 4 satellite channels to 5 channels apiece. These changes were made between missions, and the modifications had no negative effects.
  - A third lesson learned here was that the LFP missions had to schedule around periodic aircraft phase inspections and around unrelated aircraft modifications. These would often delay the planned schedule by 1-2 weeks, and force the other facilities to become available when the aircraft schedule had an opening.

- Merging several TSPI sources was advantageous. Eglin developed the TDP to merge several TSPI inputs in near real time. This robust implementation coasted through most dropouts to allow a more consistent (and ultimately accurate) solution of entity state data.
  -- The TDP combined real-time aircraft INS and GPS data to calculate more accurate kinematic estimates. In the past, it was common to use a single source of TSPI on the Eglin range. In general, the FPS-16 ground tracking radars could be very inconsistent, especially in altitude tracking, and thus be somewhat inaccurate. When the original TSPI data from the live OP-612 test was evaluated, the tracking radars appeared to have an altitude error of up to several hundreds of meters. This level of TSPI accuracy is inadequate for driving the HWIL simulation.
  -- The resulting lesson was that the TDP could provide a much better trajectory estimate by combining several sensor inputs. By merging the aircraft INS, GPS, and FPS-16 data, the TDP solutions were estimated to be accurate within 1-3 meter (m) in position and 1 meter per second (m/s) in velocity (see Section 4.3.1.3). Further, even though GPS dropout rates often exceeded 50%, the INS and radar data were available more than 99% of the time. Therefore, the periodic GPS dropouts did not significantly degrade the accuracy of the position solution, because the TDP used the accurate INS data to propagate the solution between GPS updates (see Section 4.3.1.3).
  -- The degree of TSPI accuracy achieved with TDP easily met the requirements for driving the missile HWIL simulation and allowed unprecedented direct evaluations of the shooter fire control radar accuracy to be performed.

5.1.5 Data Processing

- Data processing systems need to be tested under realistic mission loading conditions. Most of the current facilities were built for specific functions, or are stand-alone facilities which were not intended to be linked. When connecting facilities with different requirements, the processing capability of some computers was exceeded. Thus, while linking these sites together, the SIT team learned some limitations that were neither obvious nor previously tested.
  -- At the Eglin CCF, the MTACS processing system could not output the full data rate of GPS information when it was loaded with inputs from four GPS pods. Each of the four GPS pods inputs 10 data records per second, and the ground reference receiver also inputs satellite correction data to the MTACS. However, the MTACS processors could not output 10 records per second from each pod (output was limited to about 3 or 4 Hz), so the decision was made to use only one pod per aircraft.
  -- Also in the CCF, the TDP could not process the full load of INS data from two aircraft, so a much smaller sample had to be used. The INS data were generated at a rate of 50 Hz, but the TDP input rate had to be reduced to 10 Hz (from sampling the 50 Hz data), which matched the data rates from the GPS pods and the ground tracking radars. The impact of the smaller INS input rate was that the TDP output was less accurate during high-g maneuvers.

5.2 Infrastructure Lessons Learned

5.2.1 Procedural Lessons Learned

The procedural lessons are further categorized by the test phase.

5.2.1.1 Procedural Lessons Learned During Planning Phase

- Piggybacking off of other activities is not always practical. Some attempts were made to accomplish LFP objectives by leveraging off of other activities at Eglin, but these piggyback attempts resulted in months of delay and problems satisfying LFP requirements. After the AASI requirement was discovered, the AMRAAM Joint System Program Office (JSPO) contracted for its development with the prime contractor. However, uncertainty of contract criteria and schedule caused major delays in the LFP schedule. Another example was when the LFP tried to piggyback off of a live test in order to get a full set of TSPI data for the TDP load test. These attempts were unsuccessful because of approval or cost problems, and the result was that the LFP scheduled its own dedicated flight test to accomplish the TDP load test.

- A full understanding of telemetry limitations is needed. Early live flight testing showed that even short telemetry dropouts or time stamping problems caused many aborted or invalid passes; workarounds had to be made to obtain better telemetry reception.
  - First, the two wing station fuel tanks on each F-16 were removed in favor of one centerline fuel tank; even this tank caused unacceptable shielding of telemetry transmitters, so it was removed in favor of a "clean jet." This configuration provided better aircraft telemetry, but required an airborne refueling after about 45 minutes.
  - Second, analysis revealed that east-west profiles (which are parallel with the Eglin coastline) provided better telemetry reception than either north-south or diagonal profiles.
  - Third, the aircraft were flown at higher altitudes than originally desired. In order to achieve approximately line-of-sight telemetry reception, the aircraft were flown above 18,000 feet when 20-30 nautical miles offshore, and above 21,000 feet when 35-45 nautical miles offshore. This improved air-to-ground telemetry reception, and also helped the ground tracking radars to consistently track the aircraft (multipath effects were reduced when the aircraft were more than 3.5^{o} above their horizon). Also, the range controller had to understand these requirements in order to keep the aircraft in the best position for telemetry reception, even after refueling in distant sectors. (Note that using an airborne telemetry relay platform, such as an E-9 aircraft, was out of scope for the LFP effort, but could help other projects which have low altitude scenarios.)

- Pilots should be involved in scenario setup. It was very beneficial to contact the test squadron pilots in order to achieve the correct flight profiles and launch parameters. The LFP missions were based on previously flown AMRAAM profiles, and the goal was to replicate those profiles (within LFP limitations). It was difficult to match the scenario launch conditions during high-g maneuvers. The best results came when the project personnel met with the pilots to review possible setup options, then reviewed the flight plan during the pilots' premission briefing.

- A premission briefing is needed before each mission. A premission briefing was held 24 hours before each mission and was critical for coordinating the many network and flight test issues. The briefing agenda should include the test objectives, planned run matrix, personnel involved, communication plan with back-up phone numbers, show time for personnel, go/no go criteria, contingency plans in case of failures, instrumentation and data collection requirements, and details on facility configuration (shooter and target communications channels, patch panels, TSPI check-out sequence, etc.).

- Live missions require more contingency planning. Live aircraft operations required more contingency planning to quickly decide on alternatives. A great benefit for using an ADS-linked network was having several "analysts-in-the-loop" during the real-time mission. The JADS test director had to make timely decisions between the aircraft passes in order to affect the outcome or productivity of the mission. Initially, a small list of go/no go criteria was made before the first live flight. This list included criteria on key aircraft components (INS, shooter radar, radios, etc.), and on aircraft pods or ground systems. As the experience level increased after risk reduction missions, this list was expanded to include alternatives in case of failures or degraded assets. These alternatives included changing aircraft profiles, timing of maneuvers, modes of the GPS pods, computer processor swapouts, etc. Having this contingency plan spelled out in advance truly helped the test director make rapid, well-informed decisions to get the most productive use out of the remaining mission time.

5.2.1.2 Procedural Lessons Learned During Development Phase

- A strong program manager or system integrator is needed to oversee facility development. It was difficult to coordinate several diverse facilities and successfully integrate an ADS-linked configuration. The Air Force Development Test Center (AFDTC) manager had to grasp the technical and administrative issues involved and proactively resolve the problems. Within the current test range management structure, one person does not have the authority to task and manage other facilities and affect the optimal use of resources. Therefore, the AFDTC program manager had to be persistent and persuasive to solve integration problems.

- Task management tools were useful. The test team became much more organized when the AFDTC Program Manager created and published some task management tools, such as a work breakdown structure (WBS) and a corresponding schedule using Microsoft® Project software. The WBS delineated the integration tasks, and the Gantt charts on Project helped to deconflict resources. These tools were helpful to the managers, as well as the team members, at different facilities.

- Use risk reduction tests for integration. The series of risk reduction tests was extremely useful to progress through many levels of integration work. The Eglin members designed a building block approach to check out interfaces at the lowest level, then add one or two resources at a step to integrate the linked configuration. It allowed flexibility in planning some tasks, and to add on some live flight tests to the end of the risk reduction schedule. It would have been useful to allow more time between tests to research problems and implement fixes.

- Risk reduction tests were useful for developing analysis tools. Getting data during the risk reduction tests was also beneficial to create and refine some analysis tools before the formal test execution started. This early exposure to the data allowed the programmers and analysts to read the raw simulation formats, choose among statistical packages, build real-time viewing charts, make utilities to convert units, and rehearse analysis procedures.

5.2.1.3 Procedural Lessons Learned During Execution Phase

- Live aircraft must be locally controlled. During the test concept development phase, the SIT team explored control of the entire test, including the live aircraft, from a remote site (e.g., the TCAC). It was soon learned that Eglin test range safety policy required that tactical control of aircraft over their airspace be performed at the Eglin CCF. Safety concerns over aircraft control from the TCAC were aggravated by the significant latency (~2.5 sec) of aircraft trajectory displays at that location. Therefore, test control during the LFP missions had to be exercised from the Eglin CCF.

- Project and scenario control were best performed at the test range. Another issue was where to locate project decision makers to control the scenarios and test events. During early risk reduction tests, it became apparent that when handling developmental problems, there was significant discussion that was never transmitted via radio links. Much troubleshooting was still communicated face-to-face, over local intercom, or via direct phone line. Even with some display monitors, personnel at remote sites would often hear about problems late, often with only partial explanations. Therefore, in order to be part of the decision making process, the JADS test director had to be collocated with the CCF coordinator and the range aircraft controller. The CCF was the necessary choice, since it was centrally located with the critical personnel, all communication networks, and with the majority of system displays.

- Several subnetworks should be used for voice communications. Three voice communication networks were needed to support more than 30 people at various locations, and a fourth network could have further aided decision making.
  - The pilots and aircraft controllers had to use a UHF radio link, and no other personnel transmitted on that link.
  - Another network linked the CCF and instrumentation nodes on a test range intercom system. In order to maintain communication discipline, only six people actively transmitted on this intercom, while all other personnel listened on speakers and transmitted only when necessary.
  - A third network linked only the JADS logger and wide area network personnel via teleconference on a Defense Switched Network (DSN) phone line. This DSN line was

barely adequate for a 5-person conference call, as we never got the full 10-person capability, somebody would randomly get cut off of DSN during the 2-hour mission, and not all people could hear the voice transmissions adequately (usually one person had to repeat run calls, and we often bridged two conference lines).

-- In post-mission discussions, project personnel agreed that a fourth voice network just for the four main SIT team members would have further aided decision making. Each of the members observed some critical part of the network puzzle, and in a wide area network, no one person had all of the information displayed in front of him. Therefore, a fourth phone or intercom network would have helped to provide more timely inputs between project personnel and to make quicker decisions about problems.

- Two-dimensional displays were needed at each node. Using a graphical 2-D display greatly improved the situational awareness of participants at each testing site. The 2-D display converted the ES PDUs into symbols overlaid on a local area map. As a result, the team members knew where and in what direction the aircraft were flying and if the missile simulation was active.

- Existing range procedures had to be modified for ADS. The existing Eglin test procedures were only written for individual facilities, so a new combined checklist was created for ADS applications. The AFDTC Program Manager developed a new checklist which interleaved some actions from each facility in order to get proper connectivity between the CCF, MISILAB, and PRIMES. This checklist covered activities from 24 hours prior, 4 hours prior, 1 hour prior, and, of course, during the mission time.

- Lab replays served as an excellent method of rehearsal. By replaying a set of prerecorded data, all the Eglin team members could participate in a laboratory replay session. This was an excellent method to rehearse test procedures, work out technical and procedural issues, and troubleshoot problems in a low-cost, low-stress lab session. It was beneficial to do two different replay sessions before each mission, the first at one week prior and the second at one or two days prior to the mission.

5.2.2 Policy Lessons Learned

- Verification of test range assets is a test range responsibility. The range should verify range assets before use by external customers, and these same verified procedures should be used during ADS testing.

-- The TDP had never been used by an external project until the LFP, and its previous testing was not sufficient to verify that it could handle all inputs required for the LFP testing simultaneously, nor find its maximum throughput capability, nor have a standard procedural method to load it.

-- The LFP also spent two missions "reinventing the wheel" concerning aircraft configurations for clean telemetry, after which it was determined that any fuel tanks would interrupt telemetry reception.

-- Lastly, the MTACS computers could not process a full load of GPS data from four pods; early LFP risk reduction missions verified this, and subsequent missions had to back off to two pods. The use of one pod per aircraft was contrary to the initial range recommendation, and indeed those missions experienced 40-60% GPS dropout rates from fuselage shielding of the one wing station pod.

- <u>Low program priority significantly impacts scheduling for ADS</u>. The LFP missions required the use of several high-demand assets in a linked configuration. Consequently, it was very difficult to schedule these simultaneously, especially with a low priority (#246). In the CCF, the LFP used five of the seven real-time computers, so other projects could not share that time block. The F-16s and GPS pods were also in high demand by other projects, which left specific restricted days for LFP usage. The Eglin schedulers did find mission times for the LFP, then either the heavily utilized PRIMES or MISILAB would adjust their schedule to fit the LFP missions in. Having to work with two different scheduling systems was also difficult. It would be useful if range and laboratory schedules were linked together and operated off the same priority scheme.

5.2.3 Costs Lessons Learned

- Long lead times are required to procure T1 circuits. A T1 circuit was the best option for the LFP wide area network, but the contract was somewhat expensive and had difficult initiation and termination clauses. The dedicated T1 circuit cost $4448 per month with a minimum 12 month lease, and it took 120 days to initiate the circuit between Eglin and Kirtland. (Once initiated though, workarounds were found to relocate the physical termination points at each site.) Also, American Telephone and Telegraph (AT&T) wanted a 60-day notice to terminate the line, and had a $10,000 penalty for early termination of the contract.

- A detailed WBS and accurate cost breakdown are needed from the range. The range should create a detailed WBS early in the program, and try to have accurate costs estimated against the workcenter tasks in order to help program management decisions. A WBS was not drafted until 14 months into the LFP program, and the Statement of Capability costs from the range were not mapped to it. The standard Eglin accounting system is very generalized and geared towards "funds remaining," which barely helps the manager make reallocation decisions. The biggest impact was that subcontract money was spent too early in the program as development was slipping, and not much money was left for the higher priority test and analysis tasks. Having a WBS in place and costs allocated against it could have prevented those problems.

5.2.4 Personnel Lessons Learned

- High personnel turnover hurts project development. Not surprisingly, high turnover slowed development of the ADS network, and generally left voids in experience or communication. In all, nine key personnel left during the 4-year program, including both the Eglin and JADS managers, the SC software manager, three missile experts and three range experts.

- Matrix management of personnel impacted project. Several functional area experts were only parceled out to the SIT team from their matrixed organizations, which impacted the timelines of documents, network installation, and TSPI procedures. The SIT team lead preferred to have more control over personnel issues, but often had to get some expertise on a part-time basis.

6.0 Conclusions/Recommendations

6.1 Utility

6.1.1. Utility Conclusions

- The live fly phase (LFP) advanced distributed simulation (ADS) configuration has utility for missile weapon/launch aircraft system test and evaluation (T&E).
  - This configuration successfully used actual missile hardware linked to a live launch aircraft.
  - This configuration can be used for discrepancy/deficiency resolution, especially when there are interface issues/problems between/among weapon systems (e.g., the aircraft radar, mission computer, stores management system, and the missile). This includes troubleshooting problems which prove to be difficult to replicate, particularly those that appear in flight tests but are not readily duplicated in stand-alone laboratory testing.
  - This configuration permits the hardware-in-the-loop (HWIL) missile to respond to actual pre and post-launch weapon system inputs, instead of relying on stand-alone "canned" inputs, in an operationally realistic environment.
    - Real umbilical and rear data link (RDL) messages are used.
    - Real environmental factors affect the shooter fire control radar performance.
  - The use of highly accurate time-space-position information (TSPI) data permits more accurate and thorough evaluations of the accuracy of umbilical and RDL messages than was possible under previous testing.

- The LFP ADS configuration has utility for rehearsal and refinement of live fire test scenarios.
  - Pilot training and rehearsals of live missile firings requiring difficult and/or precise launch conditions could be accomplished using this configuration. ADS could assist in doing the live fire test right the first time, which translates into reduced aircraft flight hours, range time, etc.
  - The LFP ADS configuration gives immediate results on the missile performance for a given scenario and can be used as a risk reduction tool before live fire missions.

- The LFP ADS configuration has utility for operational test and evaluation (OT&E), tactics development, and some "free-play" scenarios.
  - Live aircraft are used in real environments.
  - However, the missile HWIL laboratory could not handle large angles off and/or large angle rates to accommodate some "free-play" scenarios.

- The LFP ADS configuration permits more efficient testing.
  - Quick-look results are available immediately after each pass. These results allow a verification between passes that all required data were obtained, that the profile was properly executed, that the TSPI data were of sufficient accuracy, and that the

advanced medium range air-to-air missile (AMRAAM) HWIL simulation responded properly to its inputs.
  - -- The analyst-in-the-loop ensures efficient use of live range time. The analysts can determine immediately after each pass if the pass objectives were accomplished and if valid data were obtained. This timely determination allows decisions to be made during the mission on the conduct of subsequent passes (e.g., if the missile did not appear to perform properly, the pass can be repeated).

- The LFP ADS configuration does not have utility for engagement studies involving closed-loop interactions between the missile and the target.
  - -- Latencies were much too large for this application.
  - -- Feedback loops to the live target would have to be developed.
  - -- This is not a serious limitation, since nearly all live fire testing is open loop.

6.1.2 Utility Recommendations

- Investigate the extension of the LFP ADS configuration to the following:
  - -- Multiple target/multiple missile engagements.
  - -- Electronic countermeasures (ECM) vulnerability testing that should not be done in the open air.
  - -- Low altitude engagements by the use of an airborne telemetry relay platform.

6.2 Technical

6.2.1 Technical Conclusions

- The LFP test objectives were successfully accomplished.
  - -- The verification and validation (V&V) method implemented successfully validated AMRAAM performance for the scenarios tested.
  - -- The TSPI Data Processor (TDP) achieved the required degree of TSPI accuracy in near real time: 1-3 meter (m) in position and 1 meter per second (m/s) in velocity.
  - -- Inputs to the Missile Simulation Laboratory (MISILAB) simulation were adequately synchronized.
  - -- TDP processing and data synchronization resulted in relatively large latencies for the missile flyout, more than 3 seconds.
  - -- The LFP ADS configuration was assessed as being able to support AMRAAM testing with the exception of closely coupled engagements between the missile and the target.

6.2.2 Technical Recommendations

- Investigate future improvements to enhance TDP performance.
  - -- Improve TDP processing capability, so that the full rate (50 hertz [Hz]) inertial navigation system (INS) data can be input, and a 50 Hz TDP solution can be output.
    - --- This improvement would increase the accuracy of the TDP solutions during high-g aircraft maneuvers.

--- This improvement would also allow the buffering time at the MISILAB (required for synchronization of the MISILAB inputs) to be significantly reduced, thereby reducing the total latency.

-- Use the Range Applications Joint Program Office (RAJPO) data link system to downlink and process global positioning system (GPS) pod data. This will allow the processing of two pods per aircraft and will significantly reduce GPS data dropouts due to fuselage shielding of one of the pods.

-- Examine the reduction of TDP processing time. Fully explore the trade-offs between processing time, TDP solution accuracy, and valid MISILAB HWIL performance. The TDP processing time was the single largest contributor to total latency, and reductions in processing time would lead to corresponding reductions in latency.

6.3 Infrastructure

6.3.1 Infrastructure Conclusions

- While this was a relatively simple architecture, the set-up and check-out activities consumed significantly more time than planned. A dwindling number of people have an expectation that creating a linked T&E architecture is a "plug-and-play" exercise. This test phase clearly showed it was not.

- A sequential, build-up approach to verifying network performance is necessary. Initially, a lot of attention needs to be paid to the facilities in a standalone mode so that network-driven modifications can be checked out. Only when each node has been judged "healthy" does it make sense to embark upon the assessment of the integrated architecture.

- A full-up linked architecture is necessary to validate "fixes." Many fixes cannot be adequately assessed unless the entire network is used. Test planners should incorporate these linked testing periods in their schedules and budgets --- they are not any cheaper than rehearsals.
  -- In this case, the full-up linked architecture included live aircraft, as in a formal mission. Using an architecture in which the aircraft were represented by ground facilities/simulators did not allow for valid testing of the entire network.
  -- Some fixes can be checked using the replay of data recorded from previous live flights, but full validation requires live aircraft.

- Test planners engaged in using this kind of architecture should probably plan for two attempts on every required mission. (Bear in mind this test only had three participating nodes --- as the number of nodes goes up, the planner's expectations should go down.) Additional time is necessary prior to the start of testing and at the end of each test period. The former to fine tune the network and eliminate start-up glitches, and the latter to accommodate data logging, archiving, and transfer.

- Test control had to be exercised from the test range and worked well. In a distributed test architecture, the control mechanism must support a sensible blend of centralization, test direction, level of control, and decentralization, test execution, node-level controls. The emergencies usually occur at the node level; adjustments after emergencies are usually best managed at the test direction level.

- Configuration control and the associated documentation are essential to a successful test program. An adequate management structure, with the requisite authority, must be put in place prior to the start of testing.

6.3.2 Infrastructure Recommendations

- The ability to control live aircraft from a site other than the test range should be explored. Future test teams would have more flexibility if overall test control could be exercised at a location remote from the test range.

- The LFP ADS architecture at Eglin should be upgraded to be high level architecture (HLA) compliant.

- The MISILAB HWIL facility should be replaced by the Guided Weapons Evaluation Facility (GWEF) AMRAAM HWIL facility in the Eglin LFP ADS architecture since the MISILAB facility is being phased out.

- The GPS simulator used with the PRIMES facility should be upgraded to utilize GPS satellite ephemeris data and differential corrections from the ground reference receiver. If the GPS inputs to the TDP can be corrected to represent a high-fidelity simulation of live GPS data, the PRIMES-CCF-MISILAB ADS configuration should be reevaluated for its suitability, efficiency, and cost effectiveness in supporting test planning, integration testing, and mission rehearsals in future programs.

- Future ADS development efforts should be negotiated with the range/test facilities as "cost" type contracts rather than "firm fixed price" contracts.